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THE DEVELOPMENT OF PHOTOGRAPHY IN ASTRONOMY.*

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The American Association for the Advancement of Science has now completed an existence of half a century. It has become one of the leading scientific institutions of this country. Since its organization fifty years ago the world has advanced with wonderful rapidity in all directions, and especially in the various fields of science. It is hardly too much to say that the scientific progress in the last half century far exceeds all that was done in the preceding thousand years. The life of this association practically covers the development and comparative perfection of many of the sciences. This is especially true of the wonderful art of photography. At the beginning of the work of this association the great discovery of making pictures by the natural light of the Sun had just been made, and while it aroused a widespread interest all over the world at that time there were very few who dreamed of the great future value of photography in the arts and sciences. One of these who saw something of the future of Daguerre's discovery was the celebrated Scottish astronomer Dr. Dick, whose works on popular astronomy are still useful and delightful reading. In his "Practical Astronomer," published in 1845, he said:

"It is not improbable, likewise, that this art (still in its infancy) when it approximates to perfection, may enable us to take representations of the sublime objects of the heavens. The Sun affords sufficient light for this purpose; and there appears no insurmountable obstacle in taking, in this way, a highly magnified picture of that luminary which shall be capable of being again magnified by a powerful microscope. It is by no means improbable, from experiments that have hitherto been made, that one may obtain an accurate delineation of the lunar world from the Moon herself. The plated discs prepared by Daguerre receive impressions from the action of the lunar rays to such an extent as permits the hope that photographic charts of the Moon may soon be obtained; and, if so, they will excel in accuracy all the delineations of this orb that have hitherto been obtained; and, if they should bear a microscopic power, objects may be perceived on the lunar surface which have hitherto been invisible. Nor is it impossible that the planets Venus, Mars, Jupiter and Saturn may be delineated in this way, and objects discovered which cannot be descried by means of the telescope. It might,

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perhaps, be considered as beyond the bounds of probability to expect that very distant nebulae might thus be fixed, and a delineation of these objects produced which shall be capable of being magnified by microscopes; but we ought to consider that the art is yet in its infancy, that plates of a more delicate nature than those hitherto used may yet be prepared and other properties of light may yet be discovered which shall facilitate such designs."

Had Dr. Dick lived until the present day he would be amazed to see what portions of his prediction have in a measure come true. To him the most improbable of the things he forecast for photography to accomplish was the delineation of the nebulæ, and yet it is in this direction that photographic astronomy has most decidedly excelled. To use highly magnified images for photographing the details of the planets seemed to him to be among the first triumphs that were to fall to astronomical photography; yet today they are almost as far from realization as they were in the days when good Dr. Dick charmed his readers with vivid descriptions of the wonders of astronomy. I do not think the most active imagination could have foreseen in Dr. Dick's day the marvellous extent to which astronomy at the close of the nineteenth century would be influenced by that light-picturing process just then being developed by Daguerre and others.

After all, however, it is easy in the case of great discoveries of this kind to predict what they will amount to. This is usually done by immensely exaggerating all their possibilities and thus, by a happy chance, hitting one or more of their realities, for strict account is usually kept only of the hits in such cases, the misses being rejected by a charitable world as a matter of no importance. We are used to wonders in these days of wonders, and have a happy habit—from frequent practice—of correctly guessing the outcome of some of the great discoveries. But when Dr. Dick wrote, these things were not so easily foreseen, for the possibilities of the sciences were not so apparent then as they are now.

So great have become the possibilities of photography in the astronomical investigations of today that an account in detail of its accomplishments would far exceed the limits of this paper, and for that reason I shall be forced to a brevity in dealing with this subject that must necessarily pass over many of the interesting things photography has done for astronomy in its comparatively short lifetime.

It does not come within the province of a paper of this kind to deal with the questions of priority in the discovery of photography (though something might be said on that point for America), as the process interests us only so far as its application to astronomy is concerned.

It appears that on the very first announcement of Daguerre's wonderful discovery on the 19th of August, 1839, the celebrated French Astronomer Arago, who addressed the Paris Academy on the subject, quickly foresaw the great advantage it must necessarily be to the science of astronomy, especially in the faithful delineation of the surface features of the Sun and the Moon, for these two objects, at least were bright enough to register themselves with the sluggish materials then in use. It is specially gratifying to Americans that the first efforts to utilize the new discovery for the benefit of astronomy were made in this country and that Americans have always been prominently identified with the process from its very earliest conception.

Within less than one year from the announcement of Daguerre's discovery, in March of 1840, Dr. John W. Draper, of New York City, had succeeded in getting pictures of the Moon which, though not very good, foreshadowed the possibilities of lunar photography. Five years later the Harvard College Observatory may be said to have commenced its remarkable career of astronomical photography, when Bond, with the aid of Messrs. Whipple and Black, of Boston, succeeded in getting still better pictures of the Moon with the 15-inch refractor. These pictures, on daguerreotype plates, seem to have been fairly good, and to have shown much detail, though the telescope was wholly uncorrected for the photographic rays. They attracted a very great interest in the subject, especially in England, but the difficulties encountered led to the failures generally, except in the case of De La Rue, Dancer and one or two others. To Dancer is doubtless due the earliest success in lunar photography. Excellent photographs, it is said, were made by him as early as February, 1850. In 1858 De La Rue, using a 13-inch metal speculum, without clockwork, and guiding by following a lunar crater seen through the plate, made the most important of the early efforts at lunar photography. From this time De La Rue made the best pictures of the Moon until the subject was taken up again in America in 1860 by Dr. Henry Draper, son of the illustrious John W. Draper. Like De La Rue, Dr. Draper constructed his own telescope, a 15½-inch reflector. With this instrument he secured excellent photographs of the Moon, superior to any previously made, and capable of considerable enlargement. These pictures were the best taken until Lewis M. Rutherfurd began his remarkable work about 1865. Rutherfurd's work marked the most important step until then made in astronomical photography. From this time on he produced such admirable photographs of the Moon that they have not been ex-

celled until within the past few years. These were made with a refractor of 11-inchs aperture which had been constructed under his immediate supervision. It was the first telescope corrected specially for the photographic rays. Some excellent lunar photographs, in the meantime, had been made with the great four-foot reflector of the Melbourne Observatory.

The completion of the Lick Observatory in 1888 marked another decided advance in the photography of the Moon. The great focal length of this magnificent instrument gave an unenlarged image of the Moon about six inches in diameter, which in itself was a great advantage.

The admirable lunar photographs made by MM. Loewy and Puiseux, with the equatorial coudé, at Paris, in the past few years have excelled anything yet made in this direction.

But what is shown by the best lunar photographs has not yet approached that which can be seen with a good telescope of very moderate size. The minute details are at present beyond the reach of photography, but its accurate location of the less difficult features is of the highest value. The greatest interest in any observation of the Moon would be in any changes that might take place on its surface. It has long ago been shown that no changes on a large scale have occurred in recent times. It is, therefore, to the minuter details, if anywhere, that we must look for change in the Moon, and these at present are much beyond the reach of the photographic plate.

The Sun, from its abundance of light, offered special inducements to the early workers in photography. It would rather appear, however, that the Moon had the most charm for the first photographic astronomers. This was doubtless due to the singular and wonderful wealth of detail its surface continually presented, while the Sun, except for a few occasional spots, was at best only a blank surface. But when carefully and conscientiously studied, however, it highly rewarded those who took up its study photographically.

The first picture of the Sun seems to have been made on a daguerreotype plate by Fizeau and Foucault in 1845. During the total eclipse of the Sun on July 28, 1851, a daguerreotype was secured with the Königsberg heliometer (2.4 inches in diameter and 2-feet focus) by Dr. Busch, which appears to have been the first photographic representation of the corona. It showed considerable detail quite close to the Moon. But in the early eclipses the photographic work seems to have been mainly devoted to representations of the solar prominences, which at that

time were as rarely seen as the corona itself. During the eclipse of 1869, however, Professor Himes secured a photograph which showed the brighter structure of the corona; similar pictures were also obtained during the same eclipse by Mr. Whipple, of Boston. The corona was also slightly shown on pictures made as early as 1860 by M. Serrat. None of them, however, showed more than slight traces of the corona, extending only for a few minutes of arc from the Moon's limb. Nearly all the pictures seem to have been taken with an enlarging lens, which was doubtless used to get the prominences on a larger scale. Mr. Whipple, however, in 1869, did not use any primary enlargement, and this gave him a decided advantage in point of exposure time. In nearly all of these pictures the exposures, with the slowness of the then-existing plates, were evidently too short to show the corona, except perhaps in the case of Whipple, who gave 40 seconds exposure.

The first really successful photographs of the corona were obtained at the eclipse of December 22, 1870, when it was shown on the plate to a distance of about half a degree from the Moon's limb. This picture, made by Mr. Brothers at Syracuse, Sicily, showed a considerable amount of rich detail in the coronal structure; and the same can also be said of the photographs of this eclipse taken by Colonel Tennant and Lord Lindsay's party. These seem to have been the first pictures to really show the great value of photography for coronal delineation. The eclipse of 1871 was still more successfully photographed, and an excellent representation of the corona, full of beautiful detail, was secured.

All of these pictures were made with the wet process, for the dry plate was not successfully used until about 1876, and it was five or six years later before it became generally useful or at all reliable. For some years previous to this, photographers had been at work with varied success upon different methods of preparing and sensitizing plates that could be used dry. Indeed, at the eclipse of 1871, at Baikul, India, it appears that Mr. Cherry used a dry plate on which he exposed a number of images of the Sun before totality for the orientation of the eclipse plates. It would seem that he had only two of these plates and they were both intended to be used for orientation. The second plate, however, was broken before it could be used. It is probable they were known to be less sensitive than the wet plates, which doubtless prevented their being used for the corona.

Though the pictures of 1870 and 1871 showed the value of the

photographic method, it had so far failed to show the greater and fainter extensions of the corona. In speaking of the eclipse of 1871 and the success attained by photography at that time, it is well here to mention the evil influence that the old method of drawing had upon at least one observer. A Mr. Holiday had made observations of the corona from a housetop, and thus describes the result in his report: "As soon as the eclipse was over, I came down from the roof and plunged my head into cold water, for I was violently excited, and before breakfast I had made three drawings from my memoranda." If photography has done nothing more for astronomy than to prevent occurrences of this kind it would at least deserve lasting respect from a humane point of view.

In 1878 extensive preparations were made to observe the eclipse of July 29th of that year. Photography was to play an important part, though astronomers did not rely very strongly upon it, for it appears that all were prepared to make the customary drawings of the corona, and unfortunately each person faithfully carried out that purpose. A most suggestive illustration of the uncertainty of such work is found in the large collection of drawings published in a volume issued by the United States government relating to the eclipse of 1878. An examination of these forty or fifty pictures shows that scarcely any two of them would be supposed to represent the same object, and none of them at all closely resembled the photographs. The method of free-hand drawing of the corona made under the attending conditions of a total eclipse received its death-blow at that time, for it showed the utter inability of the average astronomer to sketch or draw under such circumstances what he really saw.

At this time the dry plate was still in its infancy, and the results with it ranged from failure up to a fair picture of the corona. The greatest extension of the corona obtained, however, seemed to be about half a degree from the Moon's limb, while Professors Newcomb and Langley traced it nearly six degrees with the eye alone. The results, nevertheless, were highly important, and they demonstrated the success of photography for this class of work. One of the cameras at this eclipse was put in charge of a private soldier, with instructions to give an exposure of 65 seconds. The instructions were faithfully carried out, but as no one had told him to draw the dark slide the plate remained unexposed.

The total eclipse of 1882 proved to be of special interest, from the fact that a small unknown comet was then in the immediate neighborhood of the Sun, and was seen with the naked eye during

the eclipse. The increased sensitiveness of the plates then in use secured a strong impression of this object. The known history of the comet is comprised within the few minutes of totality of that eclipse, for it was never seen afterwards.

In the eclipse of 1886 photography again held an important position. But the extremely humid climate of Granada (one of the observing stations) and the necessity of employing volunteer observers, led to numerous disasters, such as the failure to get the Sun's image on the sensitive plate in the most important instrument; the breaking of the polar axis just before totality in the next important instrument; the failure of an assistant to make the exposures with another until totality was all but over; the fact that two native policemen stood in front of the photometer during totality; the two weeks' delay of the steamer in getting away from the island; the seizure of the plates by the custom officials on arrival at New York, and, after their rescue, the subsequent delay for want of time to develop the plates, until May of next year, when they had undergone decomposition, so that the results were not as good as might have been expected.

The closing of the year 1888 and the opening of 1889 brought one of the most important eclipses that had yet occurred from a photographic standpoint. Certainly no previous eclipse, nor any since, so far as that is concerned, was photographed by so many persons, and with such a varied assortment of cameras, telescopes, etc. The path of this eclipse lay across Nevada and California, and every photographer, amateur or professional, near the line of totality took part in the work. The amateur photographers of San Francisco and Oakland banded together under the leadership of Mr. Charles Burckhalter and photographed the eclipse in a systematic manner, the result being a most excellent collection of negatives of the corona. In some of these pictures the coronal streamers were carried to a far greater extent than at any previous eclipse; especially was this so in the photographs made by two of the amateur photographers, Messrs. Lowden and Ireland. At this eclipse the lot fell to the writer to make the photographs for the Lick Observatory. But at this time the Observatory had no instruments suitable for the work. To secure as large an image as possible with the poor equipment at hand, a 3½-inch visual objective by Alvan Clark was selected. This lens, after being reduced to 1¾ inch in diameter and mounted in an oblong box fastened to a polar axis driven by the clockwork belonging to the 12-inch equatorial, was found to give a fairly good photographic image. With this and two small photographic cameras,

nine negatives of the corona were secured. The best of these was one made with the Clark visual objective. By extreme care in development, this negative not only showed the exquisite polar systems of streamers and the details of the corona close to the Moon, but also carried the coronal extensions a great distance along the ecliptic. This was by far the most successful eclipse, photographically, of any that had yet been observed, and forever set aside as worthless the crude and wholly unreliable free-hand sketches and drawings previously depended upon.

The eclipse of December 21, 1889, was successfully photographed, among others, by Mr. Burnham and Professor Schaeberle, comprising the Lick Observatory eclipse expedition which was sent to Cayenne. It was at this eclipse that Father Perry lost his life through the trying climatic conditions. With the sickness of death upon him, this brave man, fearless in his duty, stood by his cameras and carefully carried out his program during the eclipse, only to collapse at its close and die a few days later on the vessel that was carrying him away from the fateful spot.

The eclipse of 1893 was successfully photographed in Brazil, Africa and Chile. Professor Schaeberle made arrangements for the photography of the corona on a large scale, and with his apparatus at Mina Bronces, Chile, secured a fine series of photographs with a photo-heilograph of 40-feet focus, which he mounted on a hill sloping toward the sun. The image was formed by a stationary lens five inches in diameter upon a large sensitive plate which was moved by clockwork to counteract the Sun's motion during the few minutes of the eclipse. In these pictures the image of the Sun was on such a large scale that the coronal details could be very accurately studied. Upon these plates Professor Schaeberle found a hazy ill-defined spot at forty minutes' distance from the Sun's centre. This he subsequently found on the African and Brazilian plates, taken by the English and American astronomers. This object was in motion away from the Sun, as shown by the photographs, which covered an interval of 2 hours and 36 minutes of absolute time. Professor Schaeberle believes this was a comet. It is not impossible however, that it was a mass of coronal matter moving out from the sun, such as has been shown by the spectroscope frequently to occur in the case of solar prominences. The fact that the object seemed to be connected with the sun by a coronal streamer would rather favor the explanation. The drawing given in *Astronomy and Astro-Physics*, p. 307, Vol. XIII., seems to further support this idea.

During the solar eclipse of 1896 the sky was cloudy at nearly all the stations, and especially where the most elaborate preparations had been made for photographic work. A few photographs were obtained, however, some of which, with very small lenses, showed the coronal extensions to a great length. The most important photographic work at this eclipse was the photographing of the flash spectrum, or the momentary reversal of the Fraunhofer lines which occurs when the edge of the Sun disappears behind the Moon or reappears from it, and for an instant exposes the reversing layer, which was first seen by Professor Young at the eclipse of 1870. This extremely important picture was made by William Shackelton, a young Englishman, who patiently waited and watched the spectrum at the edge of the Sun, and at the instant of the reversal of the lines exposed a plate which caught, for the first time, the fugitive bright lines which are only visible for about a second. This photograph was a triumph for photography, for the record of the phenomenon now does not rest upon the authority of any hasty observations, but remains a permanently visible record.

Our record closes with the eclipse of January 22, 1898, which was photographed in India by American and English astronomers. The photograph of the flash spectrum was successfully repeated by many observers. The coronal extensions were carried to a greater extent than at any previous eclipse, by photographs secured with a very small lens by Mr. and Mrs. Maunder. The observations at all the stations were eminently satisfactory.

In speaking of the photography of the corona it is well to mention the extremely interesting experiments of Dr. Huggins in an endeavor some years ago to photograph it without an eclipse. By the use of absorbing media, and later with extremely short exposures, he obtained very corona-like appearances, and it is not yet certain that they were not true coronal forms. Such experiments should be tried at very high altitudes in a pure atmosphere, and it is to be hoped that these efforts will be again undertaken under more favorable conditions.

The transit of Venus across the Sun's disc in 1882 was very successfully photographed, and the measures of the pictures made by the Americans has given a good redetermination of the solar parallax. A fine series of photographs of this transit with wet plates was obtained by Professor D. P. Todd at the Lick Observatory. This was six years before the completion of the Observatory.

There is no question but Janssen, of Meudon, succeeded many

years ago in making the best photographs of portions of the Sun's surface that have yet been made. These pictures show the granulation of the solar surface and the details of the Sun spots with admirable clearness. Janssen has always used the old wet-plate process, which seems to give the best results in solar work. The instrument with which his work is done is a very crude affair. The lens, 5 inches in diameter, is placed in a wooden box, which is mounted on an old camera stand on rollers. It is not provided with clock work. When Janssen wishes to make a photograph of the Sun he wheels this primitive affair, stained and daubed with nitrate of silver, from a shed onto a platform, elevates it towards the Sun, makes an exposure with a rapidly moving slit, and secures a photograph which, so far, but few have approached in excellence. These pictures are enlarged by a secondary lens in the camera box to about twenty inches in diameter. One peculiar feature of these photographs is the frequent presence of blurred regions, in striking contrast to the generally exquisite sharpness of the granular surface. These disturbed regions are believed by Janssen to be due to actual disturbances on the Sun's surface, and, therefore, to be true phenomena of the Sun. I have always had the impression that these features are simply due to the presence of small areas of bad seeing which are passing at the moment of exposure; that is, they are the effects of small local disturbances in our own air, such as every visual observer is familar with in night work. I remember having once secured a photograph of the Moon with the 12-inch of the Lick Observatory which showed just such a blurred spot on its surface. This question could be easily settled with a few exposures made a minute or so apart, for if the blurred appearance repeats itself at the same point on the Sun's disc, then it can not be due to local atmospheric disturbances. Doubtless M. Janssen has long ago decided this question, but, if so, it has escaped my notice.

For the first successful photographs of the Sun's surface, however, we must return to America. The first pictures to show this granulation and the details of the sun spots were taken by Lewis M. Rutherfurd in 1870. These pictures were also made with the collodion, or wet process.

From the importance of a more thorough understanding of the effects of the Sun upon the climate of the Earth, daily photographs of the solar surface are made at a number of Observatories, principally at Greenwich, Kew and in India. These have been kept up for a great many years. The Lick Observatory has in recent years also taken up this subject. It is scarcely probable that

a single day goes by without photographs of the Sun being made at some one of these observatories. Thus a valuable record is kept of the changes taking place on the solar surface. Just what effect these sun storms have upon the Earth is not yet definitely understood, but there seems to be an almost certain connection between some of the solar disturbances and terrestrial magnetic storms, so that when the Sun is violently agitated a corresponding disturbance of the Earth's magnetism occurs. It is not yet seen just how these disturbances may affect the weather; so far the testimony seems inconclusive, and local conditions on the Earth may fully compensate for any effect solar storms might have here. In the meantime the work done in this connection at Greenwich and other places will continue to grow in importance. One thing that this repeated and constant photographing of the Sun has proved is the non-existence of the so-called intra-mercurial planets, which before the days of photography were so frequently seen transitting the Sun, by Lescarbault and many others. No strange thing, aside from an alleged comet, which was afterwards traced to a stain on the photographic film, has been shown on any of these photographs, with the exception, perhaps, of one of the sun photographs made in India which caught a distant bird in its flight and showed clearly its head and outspread wings projected against the Sun.

Just as this continuous photographing of the Sun's surface has forever disposed of the alleged frequent transits of intra-mercurial planets, so will the photographic plate finally, when it has attained more perfection in dealing with the planets, show that many of the strange features ascribed to the surfaces of some of them do not exist.

As I have said, the early photographs of eclipses seem to have been made with the sole end in view of securing pictures of the solar prominences. This was very important at first, for by the photographs it was proved that they were true solar phenomena. Possibly also in the very first photographs a picture of the corona was considered a hopeless matter on account of the lack of sensitiveness of the plates. The eclipse of 1868 is memorable for having shown Janssen and Lockyer that the visibility of the prominences did not necessarily depend upon a total eclipse of the Sun. They found that by the aid of the spectroscope the prominences could be seen and studied at any time. This was an extremely important step, and placed our knowledge of the nature of the prominences upon a firm and lasting footing. The fact that these objects could be made visible with the spectroscope soon

suggested to Professor Young the idea that they might also be photographed at any time; and in 1870 he made efforts to secure impressions of them upon the photographic plate, and met with partial success. To successfully photograph these objects, however, required the invention of a special instrument, for the older methods must necessarily result in failure. In observing the prominences visually with the spectroscope it is necessary to examine them through a slit which is very narrow compared with the height of the prominences. Only a small section of the prominence can, therefore, be seen at once, and to see it all the slit must be moved over the prominence. If the slit is widened more of the object is shown, but at the same time such a flood of light is admitted that it is lost in the glare. If an instrument could be devised whereby the slit could be moved in front of a photographic plate, successively exposing to the plate all parts of the prominence, it will readily be seen that the entire image could be photographed. To do this there must be two slits moving in perfect unison—one placed across the Sun in front of the grating or prism, the other in front of the photographic plate and adjusted perfectly to the spectral line of the prominence so as to exclude all light save that emitted by the prominence itself, and thus, by the gradual motion of these two slits, the entire object is successively uncovered and an exact photograph secured of it.

The solar prominences consist mainly of incandescent hydrogen and calcium. The best results are secured by calcium alone. It is curious to see photographs of the same prominence made by using the hydrogen or calcium lines independently; these pictures often differ considerably, thereby showing the peculiarity of distribution of the calcium and hydrogen in the same prominence. The two components are differentiated, and it is thus shown just what part each component takes in the composition of the prominence. To make one of these pictures takes several minutes of exposure, during which time the slits slowly travel over the region of the prominence. This extremely ingenious device owes its existence to the inventive genius of Professor Hale, who devised and built the first instrument of this kind, and secured the first actual spectroscopic photograph of the prominences. The first pictures were made in 1891. It is, therefore, now a matter of no great labor to make not only photographs of single prominences at any time, but through a further ingenious extension of the possibilities of the instrument it is made to move across the entire Sun's disc, thus securing every prominence at that time visible. By hiding the Sun's image by an occulting disc in the first sweep,

and then making a second similar but more rapid sweep with the Sun's image uncovered, the Sun itself with all its faculæ, spots, etc., is impressed in the blank space left for it, and a complete picture of the Sun and all its surroundings, with the exception of the corona, is secured. These pictures however, show only those features of the Sun which are due to hydrogen or calcium, and the solar surface thus appears very different from the telescopic view of it. The calcium regions come out with extraordinary distinctness, so much so, indeed, as at times to completely obliterate the Sun spots, which at that moment are so distinct to the eye with the same telescope. Admirable work of this kind has also been done by M. Deslandres, of the Paris Observatory, who has devised an instrument similar to that of Professor Hale.

From the first photograph of a star by Bond in 1850 to the present time, stellar photography has gradually risen to a prominence as remarkable as it is important. The real increase of importance in this work, however, has occurred within the past ten or fifteen years, since the successful introduction of the very rapid dry plate. The wet, or collodion process was poorly adapted to the photography of the stars, and of no use whatever for comets and nebulæ. As implied by the term 'wet process,' the plate must remain wet through the entire work from its first coating with collodion until its final washing as a negative. The exposure time must, therefore, be very limited. Not only was the exposure of limited duration (from fifteen to twenty minutes), but the plate was very slow in its action compared with the dry plate of today. The combination of these two difficulties made it impossible to photograph anything except the brighter stars. Dr. Gould at Cordoba managed to increase the exposure time by keeping a stream of water playing over the plate. This, however, might cause a deterioration of the film. With the inherent difficulties of the wet plate to contend with, it is little wonder that no faint stars, nebulæ or comets were photographed. Notwithstanding this, the photographs of the star clusters, etc., of the southern skies obtained, under the direction of Gould with an 11-inch photographic refractor by the wet process, were of the highest value, and showed, upon measurement, a striking agreement in accuracy with visual work. The same can be said of Mr. Rutherfurd's photographs of the Pleiades, Præsepe, etc., which were made prior to Dr. Gould's, and which were the first photographs of this kind. These extremely valuable photographs of Rutherfurd are now receiving a most thorough measurement under the careful super-

vision of Professor J. K. Rees, of Columbia College, where Mr. Rutherfurd's negatives are stored. To this institution Mr. Rutherfurd left his telescope and measuring instruments.

In 1857 Bond had shown, by measurement of a series of photographs of the double star Mizar, that the highest confidence could be placed in measures of star plates. This has been fully verified in late years by Gill, Elkin and others. Dr. Elkin showed, in 1889, that measures of a photograph of the Pleiades taken by Mr. Burnham, with the great telescope at Mt. Hamilton, had equal value with his heliometer measures of the same stars.

From the necessary conditions, the collodion process could make no advance in stellar photography. Previous to 1876 experiments had been made to get a workable dry plate, and for the next six years more or less success had been attained in their manufacture. But the photographers themselves took hold of these plates with much caution because of their uncertainty. By 1881 or 1882, however, they were beginning to be used and gave considerable promise of their ultimate value, as was shown by the photographs of the comet of 1881, which were made by Draper and Janssen. These were the first photographs ever taken of a comet. Efforts had been made to secure pictures of Donati's comet in 1858, but without success.

At the present time these plates are made so sensitive that a rifle bullet can be photographed in full flight; yet some of the celestial objects now photographed are so faint that it requires many hours exposure with these same plates to show any trace of them.

In the fall of 1882 the world was thrilled by the advent of a magnificient comet which suddenly appeared near the Sun in September, and for the next four or five months delighted astronomers with the splendor of its display. Attracted by the great brilliancy of the comet, Dr. Gill, at the Cape of Good Hope, with the aid of a local photographer and his photographic lens, secured a fine series of photographs of the comet with dry plates. When these photographs reached the northern hemisphere they attracted a great deal of attention, not only on account of the comet itself, but also from the number of stars that were impressed on the plates. At this period the Henry Brothers were making a chart of the stars along the ecliptic in their search for asteroids. They had at this time reached the region of the Milky Way, and the marvellous wealth of stars they encountered upon entering the boundaries of that vast zone completely discouraged

them in their endeavors to carry their charts through the rich region traversed by the ecliptic. While hesitating as to the advisability of continuing their work, the photographs of the great comet came to their notice. They were struck with the great number of stars shown on these pictures along with the image of the comet. The idea at once occurred to them that they could use this wonderful process to make their charts. It was to this simple incident that the active application of stellar photography of today is due. They began at once the construction, with their own hands, of a suitable photographic telescope of 13½ inches diameter for the photography of the stars. This instrument was soon finished, and the astronomical world knows today what wonderful results these men produced with it; the exquisite star pictures which were marvels of definition, the photographs of the nebulæ, of Saturn and Jupiter, the Moon, etc., were perfect revelations.

In 1859 Tempel, at Florence, Italy, had found a diffused cometary-looking nebula connected with and extending southwesterly from the star Merope, of the Pleiades. From that time on astronomers wrangled over this object, which many of them believed had no existence. One of the first things done by the Henry Brothers was to photograph the Pleiades. These pictures showed nebulous strips near Merope, and though they did not resemble any that had been drawn by the numerous observers of the Merope nebula they rather confirmed the existence of Tempel's object. Upon these plates was shown a new nebula connected with the star Maia where none was previously known. It required the most powerful of existing telescopes to verify this visually. This was finally done, however, and it then began to dawn upon astronomers what great possibilities lay in the photographic plate for the detection and study of the nebulæ. It was soon seen that their light was strongly photographic; that it was really more actinic than visual. A later photograph with a longer exposure showed the Merope nebula just as the best observers had drawn it, and at the same time filled the entire group of stars with an entangling system of nebulous matter which seemed to bind together the different stars of the group with misty wreaths and streams of filmy light, nearly all of which is entirely beyond the keenest vision and the most powerful telescope. This was a revelation. The question had often been asked whether it would ever be possible to photograph as faint a celestial body as could be seen with a powerful telescope. Here was the answer. It was not only possible to photograph some of the faintest objects seen in the telescope, but it was possible

also to photograph some others which could never be seen in the sky. In one of his reports Admiral Mouchez called attention to the fact that the only way they could see the satellite of Neptune at the Paris Observatory was on the photographs made by the Henry Brothers, for they had no telescope sufficiently powerful to show it visually.

The Henrys applied themselves assiduously to celestial photography, with the most remarkable success. They led the world in this work. While they were at the height of their activity astronomers elsewhere were but beginning to awaken to the great importance of the subject. And yet there seems to have been essentially no public recognition of the work of these two men, to whom astronomy owes so much. In personal appearance and temperment they are so extremely dissimilar that one would scarcely take them to be brothers. Up to the time they began their photographic work they had between them discovered fourteen asteroids, by the slow and tedious visual process of picking them out by their motion from the countless thousands of small stars. If one examines a list of the asteroids he will be struck with the manner in which these fourteen small planets are recorded. According to this list the first one of these was discovered in 1872 by Prosper Henry, the next one by Paul Henry, and so on, alternately, throughout the entire fourteen, until 1879, when the last one found was attributed to Paul Henry. It is a curious fact, and one which will be readily understood by all who are acquainted with the unselfish affection existing between these two brothers, that the credit for the discovery of these fourteen minor planets is acribed alternately to Prosper and Paul Henry. It is likely we shall never know which brother discovered any one of these planets.

Singularly enough, the photographic plate not only did away with the necessity of making these charts by eye and hand to facilitate the discovery of asteroids, but it also did away with the necessity of the charts themselves for that purpose, for the little planet, which is moving among the stars, now registers its own discovery by leaving a short trail—its path during the exposure—on the photographic plate. The first of these photographic discoveries of asteroids was made by Dr. Max Wolf in 1892. They are now found wholesale in this manner by photography.

It was the success of the Henry Brothers' work that led to the International Astro-Photographic Congress which met at Paris in 1886. It was their work that caused this Congress to meet at

Paris. The Congress adopted the Henry Brothers' lens as a model for the instruments to be used, and the work of this great undertaking was based on that of the Henry Brothers. It was stated once by Admiral Mouchez that every object glass at the Paris Observatory had either been made by the Henrys or refigured by them.

Perhaps, as Dr. Dick himself thought in the early days of photography, the most unpromising subject for the photographic plate to deal with was the nebulæ. Most of these objects appeared so feeble in their light that but little encouragement in that direction was offered the celestial photographer.

One of the brightest and most promising of the nebulæ is that in the sword of Orion, and this was naturally one of the first of these objects to receive photographic attention. In September, 1880, Dr. Henry Draper began the photography of the nebulæ with this object, and succeeded, with 51 minutes' exposure, using the dry plate, in getting a good picture of the brighter portions of the nebula. This was the first nebular photograph. With 104 minutes' exposure in March, 1881, with an 11-inch refractor, he secured a still better plate, which showed stars down to the 14.7 magnitude, which were visually beyond the reach of the same telescope. But in March, 1882, he obtained the best picture of this wonderful nebula, with an exposure of 137 minutes. These pictures marked a new era in the study of the nebulæ. When these results were communicated to the French Academy by Dr. Draper, Janssen took up the subject with a silver-on-glass mirror of very short focus, having the extraordinary ratio of aperture to focus of ⅓; the aperture being 20 inches, with a focus of 63 inches. This remarkable instrument was constructed in 1870 for the total solar eclipse of 1871. With this Janssen found it easy to photograph the brightest parts of the nebula with comparatively short exposures. This extremely powerful photographic instrument seems to have been unused for the past fifteen years; but very recently it has been brought into use again, I understand, with the most astonishing results in photographing the nebulæ. Unfortunately for science, the death of Dr. Draper, in 1882, put a stop in America to the work he had inaugurated. But it was at once taken up in England by Common, who, with a three-foot reflector, attained rapid and immediate success. His photographs of the great nebula of Orion are still classic. They were a great advance over the work of Draper, for the reflector was not only a larger telescope, but was also better adapted for photographic purposes, and especially for photogarphing the

nebulæ. In January of 1883, with only 37 minutes' exposure, he secured what was by far the most striking and beautiful picture which had yet been taken of the great nebula. These pictures greatly extended the region of nebulosity, and the delicate details were also better shown.

The writer remembers how much he was impressed a few years later with the beauty of one of Common's photographs. It created in him the first ambition to do work of this kind. Indeed, this picture, and one of a densely crowded region of a part of the constellation of Cygnus, by the Henry Brothers, first called his attention to the great value of the photographic plate for astronomical purposes. It was at this time that the writer conceived the idea of photographing the Milky Way, though the experiments were not then successful for the want of a proper instrument. The great nebula, which has always had such a fascination for astronomers, was subsequently taken up by Isaac Roberts, who, by very prolonged exposures, still further extended the nebulous region and secured very beautiful pictures of it. Among the finest photographs of this object that have been made in recent years is one taken by Dr. H. C. Wilson at Northfield, Minn., with an 8-inch photographic refractor with an exposure of nine hours. The amount and sharpness of detail shown on this beautiful photograph is very striking, and essentially embraces all that has been done on this nebula by photography up to the present time.

The great nebula of Andromeda has been known to astronomers for upwards of a thousand years, as it is a rather noticeable object with the naked eye. It has received its full share of attention ever since the invention of the telescope. It also appears to be a vast body of gaseous matter shining far away in the depths of space, but it seems to be in a different condition from that of the great nebula of Orion, for its spectrum is continuous and does not show the bright lines, indicating an incandescent gas, which are present in the spectrum of the Orion nebula. Though the mystery of its physical condition has not yet been solved, photography has at least shown us its true form. It has ceased to be the long spindle-shaped body of the elder Herschel, or the broad irregular object, with two dark parallel channels in one side, as drawn by the Bonds and Trouvelot. The photographic plate reveals to us in their place a beautiful symmetrical mass of nebulous matter, surrounded with several more or less concentric rings, claimed by some astronomers to be a representation of the nebular hypothesis of La Place in full

operation. The first picture to show the true form of this wonderful object was taken in 1885, with a 20-inch reflector, by Roberts. It does not, however, require a powerful photographic telescope to show its peculiar features, for a 6-inch portrait lens will show the rings well with anything above one hour's exposure.

Important photographs of some of the spiral nebulæ, and especially of the 'whirlpool nebula' of Lord Rosse, were made as early as 1888, by von Gothard, with a 10-inch reflector. Excellent photographs of these objects have also been obtained by Dr. Roberts.

While it is absolutely necessary to use a considerable photographic telescope for the accurate registration of star positions, etc., where measures of precision are required, there are a great number of objects in the sky which are not necessarily subject to measurement, and which for their greatest value require a simple pictorial representation. The Milky Way, one of the most beautiful and certainly the most stupendous of the celestial features, is not susceptible of accurate measurement. The individualizing and measurement of all its stars would be the most hopeless task imaginable. Nor would such a task be of any very great importance could it be accomplished as a whole, for we could not form any special idea of its structural peculiarities from such a work. Though a conspicuous object to the unaided eye, the view we thus get of it is not sufficiently tangible, from the lack of details, to enable one to form any more than a crude idea of its coarser features. But even the naked-eye view of it is far more comprehensive than a catalogue would be containing accurate determinations of all its individual stars. What is required, therefore, in the study of this wonderful object—this mighty universe of stars—is something that will increase the penetration of our vision, and at the same time give us a certain amount of accuracy of position with a large field of view, so that we may study its peculiarities of structure in detail, and at the same time closely locate these details with reference to the whole, and thus, by finally putting structure and detail together, form a comprehensive idea, not only of the details themselves, but also of the relation of these features to each other. The long-focus telescope with a very limited field is not capable of dealing with the Milky Way in the manner stated. Its structural details are very large, far larger in general than the field of view of the ordinary photographic telescope, and vastly greater than that of a powerful visual telescope. We want, therefore, a

short focus instrument, one capable not only of taking in a wide part of the sky, but also of giving a brilliant image, or, in other words, the reduction of the large details to a smaller scale, with a correspondingly great increase of effective light-power. These conditions exist in the large portrait lenses which were needed in the early days of photography to reduce the exposure time by collecting a great quantity of light from the object, and which in these days of rapid dry plates are no longer required for portrait work. Taking in some ten or twelve degrees of the sky, these lenses are specially suitable for photographing large surfaces, such as are presented by the Milky Way.

This subject was taken up by the writer in the first part of 1889 at the Lick Observatory, with a large 6-inch portrait lens of 31 inches focus, and with it was inaugurated the photography of the Milky Way. The first picture to show the real structure of the Milky Way was made in 1889, with this instrument. In the few following years a large series of photographs of those portions of the Milky Way seen from the northern hemisphere was made. The work with similar instruments was next taken up by Dr. Max Wolf, in Germany, who has also succeeded in making excellent pictures of the Milky Way. Mr. Russell, of Sydney, New South Wales, has also photographed portions of the southern part of the Milky Way, with a large portrait lens. Those who have seen some of the Milky Way photographs taken with the regular Astro-Photographic telescope, or who have tried to make out its complex structure with a visual telescope, must be struck with the great beauty of a photograph made with one of these short focus portrait lenses. The extraordinary complexity of structure of the Milky Way is brought out with marvelous beauty of detail, and the peculiarities of its different portions can be traced and connected in the different photographs, which thus afford the most direct means for studying every feature of structure and detail. These pictures show many peculiarities which must materially alter our ideas of the constitution and structure of the Milky Way. Some of them show strong evidence that the general body of the Milky Way may be made up of small stars which are not at all comparable with our Sun in dimensions. This is especially shown in the region of the star Rho Ophiuchi. Many parts of the Milky Way appear to be comparatively thin sheetings of stars with relatively no very great depth, for it is not possible otherwise to explain the black holes and rifts shown in them. One of the most important revelevations made by the portrait lens in connection with the

Milky Way is the presence in it of very diffused nebulous matter apparently freely mixed with the groundwork of stars, and seemingly showing no definite tendency to condensation about the individual stars. These photographic nebulosities of the Milky Way are apparently of a different nature from the ordinary nebulæ of the sky, since they are extraordinarily large, diffused and but feebly luminous. These nebulous regions seem to be peculiar to the Milky Way and its vicinity, and are certainly in some way physically connected with it. It will be in the study by photography of such regions that we shall finally clear away some of the mysteries of the Milky Way. These masses of diffused nebulosity mainly affect regions of the sky in Scorpio, Cygnus, Cepheus, Perseus and Monoceros. I believe it to be true that no other form of telescope but the old time portrait lens or similar combination is capable of dealing with these extraordinary objects.

It was not until the study of the peculiarities of comet tails with portrait lenses that we knew anything of the strange phenomena shown by them. It may be said that our knowledge of the extremely rapid transformations in the tails of comets dates from the photographs of Swift's comet of 1892, taken at the Lick Observatory with the lens previously mentioned and similar ones taken of the same object by Professor Pickering at Arequipa. Although the great comet of 1882 was successfully photographed, it showed no phenomena not known and already seen with the telescope. While only an insignificant affair visually, and but fairly visible to the naked eye, Swift's comet showed upon the photographic plates the most extraordinary and rapid transformations yet seen in any comet. One day its tail would be separated into at least a dozen individual streams and the next present only two broad streamers, which a day later had again separated into numerous strands, with a great mass, apparently a secondary comet, appearing some distance back of the head in the main tail, with a system of tails of its own. This remarkable appearance was the first known of its kind, though it was repeated in photographs of Rordame's comet of 1893 taken by Professor Hussey. These peculiar phenomena seem to be a production of the comet itself—a result of the forces at work in the head of the comet.

The photographs of Brooks' comet of 1893, also secured with the Willard lens, showed such an extraordinary condition of change and distortion in the tail as to suggest some outside influence, such as the probable collision of the tail with some resist-

ing medium, possibly a stream of meteors, such as we know exist in space. The long series of photographs obtained of this comet frequently showed great masses of cometary matter drifting away into space, probably to become meteor swarms. One of the pictures showed the tail of the comet streaming irregularly as if beating against a resisting medium and sharply bent at right angles near the end, as if at that point it encountered a stronger current of resistance. All of these wonderful phenomena would have been unknown to astronomers had it not been for these photographs, and the comet, instead of proving to be one of the most remarkable on record, would have passed without special notice. Though these phenomena were so conspicuously shown, scarcely any trace of the disturbance was visible with the telescope. On account of the apparent insignificance of the comet visually, no photographs were made of it elsewhere during its active period.

In the matter of discovery the photographic plate has accomplished a very great amount in certain directions. In spectroscopic work it has a field singularly suited to display its possibilities. In this direction it deals not alone with what can be seen, but it enters into the unseeable regions where the eye takes no cognizance of things. For though it is partly blind to the light which affects the eye, it can readily penetrate regions where we in turn are blind. And it is in this direction mainly where the photographic discoveries in spectrum analysis are immediately concerned, since it extends our vision into the invisible regions of the spectrum. The result must necessarily be one of discovery. It not only faithfully records spectral lines that cannot otherwise be seen, but by special treatment of the plate it also registers those visible to the eye and permits their accurate measurement.

From Doppler's principle it is known that the spectral lines have a normal position only while the object whose light is under examination is motionless in the line of sight. When it is in motion to or from us these lines are displaced from their normal position, in the first case towards the violet region of the spectrum, and in the other towards the red. By comparing any of the lines in the spectrum of a heavenly body with the same lines in the spectrum of a stationary object it is possible to tell not only the direction of motion of the moving object, but to accurately determine the amount of this motion, for there is a known relation between the amount of displacement and the actual velocity, and this is independent of the distance.

This peculiarity, besides showing the motions of the individ-

ual stars, has revealed to us, through the aid of photography, an entirely new class of bodies, the so-called spectroscopic binaries.

The visual spectroscopic work long ago, in the hands of Dr. Huggins, had shown the displacement of the spectral lines as the stars moved towards or from us. It remained, however, for photography to further extend this remarkable work by showing that not only were the lines displaced, but that in the case of certain of the stars the lines were periodically doubled at short intervals, thus indicating the presence of two bodies which must be rapidly revolving about each other. The doubling of the lines is due to the alternate approach of one and recession of the other body, which thus causes a displacement of the two sets of spectra, for when the motion is at right angles to the line of sight (and this must occur at two points in the orbit) the two spectra will be exactly superposed. It can readily be shown from the known periods of these stars and their enormous distances that no telescope is likely to be made so powerful as to show visually their independent components. The visual double star having the shortest period is one discovered by Burnham, and known as Kappa Pegasi, which he found to have a period of about eleven years. The spectroscopic binaries seem to revolve in extremely short periods—a few days—and in at least one case in a few hours, showing that they must be extremely close to each other. The explanation, to account for the observed peculiarities of their spectra, that these are actual double stars in rapid orbital motion must be accepted until some better explanation of the phenomenon be forthcoming, which does not at present seem likely to occur.

Among the first of these spectroscopic binaries discovered was Beta Aurigæ, which was detected at Harvard College Observatory by Miss Maury, through the doubling of its spectral lines as shown on the various photographs obtained of it at that Observatory. This star has a period of four days, the relative motion of the components about each other being about 150 miles a second, and the distance between them about six millions of miles. In a similar manner, Dr. Vogel has found that the star Algol, so famous for its light variations, alternately approaches us and recedes, in a manner that can only be explained at present by the revolution of that star about some other body or about the center of gravity of the two. The spectrum of this star does not show any doubling of the lines, but a simple displacement from one side to the other of their normal position occurs consistent with the changes of the star's light. As there is no doubling of

the lines, the conclusion is that there is but one spectrum. One of the stars is, therefore, a non-luminous body, and hence produces no spectrum. The old explanation of two hundred years ago, that the variations in the light of Algol is due to a dark body revolving about it and partially eclipsing it at intervals of a little less than three days, is hence proved by the spectroscope and photography to be the correct one. The frequent discovery of these spectroscopic binaries shows that they are by no means uncommon, and that possibly a considerable percentage of the stars consist of two or more bodies rapidly whirling about each other.

The beautiful phenomenon of the displacement of the spectral lines through motion in the line of sight has given rise to many important and interesting results, but certainly none more striking than that offered by Professor Keeler's spectroscopic proof of the meteoric constitution of the rings of Saturn. It was suggested soon after the discovery of the rings that they must be made up of discrete particles revolving in zones about the planet, which, from their smallness and great distance from us, gave the appearance of a system of solid rings encircling Saturn. This had been shown by Clerk Maxwell to be a mathematical necessity, and as the rings lay within Roche's limit, within which a large solid body would be broken up in revolving about a planet by the unequal attraction of the planet itself, it was certain that the rings must consist of small individual bodies. It remained for the spectroscope, through the aid of photography, to add its testimony to that of mathematical analysis. The problem offered to the spectroscope was simply to show whether the inner or outer portion of the rings moved the faster. Should they revolve as a solid body the outer edge must necessarily have the greater velocity. But if they are made up of individual particles, then the attraction of the planet would cause those nearest to it to move the fastest, or, in other words, the inner part of the rings must have the greater velocity. This beautiful problem was successfully solved by the photographs of the spectrum of the rings obtained by Professor Keeler, where the displacement of the spectral lines by motion in the line of sight showed that the inner portion of the rings moved faster than the outer, and hence that the rings must consist of small bodies responding individually to the attraction of the planet.

The discovery of variable stars by photography can be compared with the wholesale business in commercial circles, because of the great number that are found on the various plates. These stars are not only found by the actual variation of their light, as

shown by the size of their images on different plates, but many of them also show peculiarities in their spectra which at once stamp them as being members of a certain class of variable stars. So expert has Mrs. Fleming, of the Harvard College Observatory, become in detecting these bodies by their spectra that she instantly recognizes them at a glance among hundreds of other spectra on the same plate. The most interesting and important of these Harvard College variable-star discoveries, are found in the photographs of the globular clusters taken by Professor Bailey with the 13-inch telescope at Arequipa, Peru. It was found that a great many of the small stars that make up these clusters varied regularly and rapidly in their light, and in some cases a large percentage of the entire mass of stars was variable. So abundant are these variables, indeed, that as many as a hundred of them have been found in a space in the sky that would be covered by a pin's head held at the distance of distinct vision.

The clusters most prolific in variables are M 3, Omega Centauri, M 5, and a few others of this class. Perhaps the most remarkable circumstance, outside of the actual grouping of variables in such great numbers, is the fact that not a single variable star has been found in the great cluster of Hercules, the best known of these objects, and apparently like them in all other respects. Professor Pickering finds every star in this cluster constant in its light from the photographic evidence extending through ten years. This would seem to mark this great cluster as being physically very different from the others referred to.*

The writer has examined the cluster M 5 with the great telescope of the Yerkes Observatory and has visually verified a number of these variables. The brighter of them appear to vary slowly in their light, while many of the smaller ones are extremely rapid, passing through their entire light changes in a few hours. In the discovery of such objects, photography offers special advantages, since on the different photographs a thousand or more stars can be rapidly and accurately compared with each other and any variation in their light at once detected, while such comparisons in the actual sky, visually, would be limited to a very few stars. By the aid of the Harvard photographic plates over five hundred variable stars have been discovered in these clusters. It must be said, however, in speaking of the variables in the cluster M 5, that the two most prominent ones were really

* Professor Bailey has since found that two of the stars of this cluster are slightly variable.

discovered visually nearly ten years ago by Mr. D. Packer with a very small telescope. These two seem to have been the first of the variable stars found in this cluster.

The shortest period variable so far discovered in the globular clusters—indeed, the shortest known variable—is a small star in the great southern cluster Omega Centauri, whose period is seven hours. These cluster variables seem to form a distinct class from the ordinary variable stars. It is very interesting to watch one of these small stars in a powerful telescope and to see with what quickness it passes through its light variation. One of the small stars in M 5, whose period is $12^h.\ 31^m.$, seems to be dormant for a large part of the time, as a very faint star, invisible in ordinary telescopes. It begins to brighten, and in two or three hours has risen nearly two magnitudes and faded again to its normal condition, while another and larger star quite near it seems to require a month or more to go through its light fluctution.

Frequent reference has been made to the photographic work of the Harvard College Observatory. It is to be regretted that time does not permit a more detailed account of this work. No other Observatory is so active in the application of photography to the various departments of astronomy. Not content with the available sky as seen from the northern hemisphere, Professor Pickering wisely established a branch Observatory at Arequipa, in Peru, where a thorough photographic survey of the southern skies has been made, and a vast amount of work of high value has been accomplished, which has resulted in many important discoveries among the southern stars.

In dealing with the ordinary stars of the sky it has been shown that measures of the relative positions of the photographic images are strictly comparable with meridian circle work, while the number of stars that can be measured is vastly greater. The Pleiades, the cluster of Perseus, Præsepe in Cancer, etc., have all been measured with the micrometer, the heliometer and by photography. The comparisons have shown that photography has many advantages over the older methods, and the results are possibly even more accurate. These objects, however, are loose clusters, and the stars are not thickly crowded, and, moreover, the small scale of the photographic plate does not in such cases seriously interfere with the work. The great globular clusters of the sky, however, from the extraordinarily crowded condition of their stars, would almost forbid any attempt to deal with the individual positions by photography, except in outly-

ing regions, where the stars are thinly scattered. No comparison between photographic and visual measures of such objects has yet been made, because no visual measures exist. The great cluster of Hercules is, perhaps, the easiest of these objects, both visually and photographically. It requires, however, a powerful telescope to measure the individual stars. Dr. Scheiner has given a catalogue of 833 of the stars of this cluster measured on photographs taken with the 13 inch refactor of the Potsdam Observatory. The stars that were measured all lie between the magnitudes 11.7 and 14. As a matter of comparison with visual measures, the writer has taken up the measurement of a few stars contained in Scheiner's catalogue. A rough inspection of the results so far obtained shows a close agreement between the visual and the photographic work. These observations also show that no appreciable change has taken place in the positions of any of the stars in the past six years, which, perhaps, is surprising, since one would expect a possible rapid change in some of the positions of the individual stars where they are massed so close together. They, however, seem to be as stable in their relative positions as are the stars elsewhere in the sky. A more remarkable object with a great telescope is the cluster Messier 5, in which the stars are more closely compressed and irresolvable than in the cluster of Hercules. This object has already been mentioned in speaking of the variable stars discovered at the Harvard College Observatory. The measurement of nearly 100 of these small stars has been undertaken with the great telescope of the Yerkes Observatory. Many of them are apparently in the very heart of the cluster, where the compression is the greatest. It is doubtful if at this time photographs can be made of this cluster upon which the crowded individual stars can be accurately measured. It has been frequently photographed, but no measures have been made of the great mass of stars in the center of the cluster.

It has been already stated that the accuracy of the photographic positions of individual stars is as great as the best meridian observations. The facility and ease with which the photographic positions are obtained is well shown in a report by Professor H. H. Turner, who is making the Oxford portion of the great Astrographic catalogue. An average of 3,951 measures per week is obtained. Over 150 stars per hour each can be measured by those most skilled in this work.

In the discovery of nebulæ, variable stars and asteroids, the photographic plate has done a great work which is still being

carried on. The number of known asteroids has been doubled in the past few years (as many as nine have been found in a single night), and now it has become a matter of impossibility to keep track of them all, and they are found and turned adrift again unless they show some striking peculiarity of orbit.

Up to the present time but two comets have been discovered by photography. The first of these was discovered on a photographic plate taken by the writer on October 12, 1892, with the 6-inch Willard lens of the Lick Observatory, and was subsequently verified visually and observed at the different Observatories. The second was photographed at the same Observatory by Mr. Coddington, with the same instrument, in July, 1898.

In photographing the sky it is found that the short focus portrait lens, from its small scale and large field, will show faint nebulosities beyond the reach of the larger photographic telescopes. This results from various causes. The action of these lenses upon the Milky Way, comet's tails and the great nebulosities of the sky does not seem to be strictly subject, in practice, to the law of the ratio of aperature to focus; or, if it is, this law must be somewhat modified in effect. The action seems to be quicker with the short focus lens than it should be. Probably, however, much of this is due to the small scale and the consequent compression of the image into a smaller space, which would produce on intensification of its action. It is possible, also, that the photographic plate may be relatively more active with a bright image than with a faint one, which would give an advantage to the small relatively bright image of the portrait lens. The idea seems to be partly borne out by some experiments with a small lantern lens. This lens, 1½ inches in diameter and about 5½ inches focus, is much quicker than its light ratio would warrant, for it will photograph in a few minutes what the ordinary quick-acting portrait lens would require several hours to show. This was strikingly shown in photographs taken with it of the Milky Way. The scale of this lens is very small, and the cloud forms are so compressed that they act as a surface, and not as an aggregation of individval stars, as they must do in a larger telescope. If the focus is increased, the stars are scattered and the cloud no longer acts as a surface. With this small lens the earth-lit portion of the new Moon was readily photographed in a single second, while with a 6-inch portrait lens of ratio $\frac{1}{5}$ from 20 to 30 seconds were required to show it well. The brighter cloud forms of the Milky Way were shown in from 10 to 15 minutes' time, while with the larger lens upward of three hours

were required. Some of the diffused nebulosities of the Milky Way, notably in the region of Antares, are shown more quickly and more satisfactorily with this small lens, and a great wing-like nebula involving the star Nu Scorpio was discovered with it.

A list of discoveries made with these small lenses would be tedious; one of the most interesting, however, cannot be passed over because of its importance. There is no object in the entire heavens better known than the great nebula of Orion. With the lantern lens, a great curved stream of nebulosity was shown on the plates of this region covering a large portion of the constellation and some 17° long. It was found later that this had already been discovered by Professor W. H. Pickering with a 2½-inch lens in 1889. This object seems to be an outlying appendage of the great nebula. The discovery, very much extends our knowledge of the complicated and far-reaching influence of this mysterions object. In several other cases the photographic plate has shown us that the nebulæ are far vaster than we had ever conceived them to be, for their fainter extensions are not seen by the eye. What this knowledge may ultimately lead to in the reconstruction of our ideas of space and its contents can hardly be anticipated just now, though it must, necessarily, very greatly influence those ideas.

We have spoken of the Pleiades and the entangling nebulosities shown by photography to involve the stars of the cluster. The portrait lens has shown us that not only are the individual stars of this group involved in a nebulous system, but that streams and masses of this filmy matter stretch out for great distances all about the cluster.

The photographic plate has shown itself especially adapted, when used with the rapid portrait lens, for the accurate registering of the paths of meteors, and it promises to be of special value during the expected return of the November meteors this year, when a more exact determination of the radiant will be obtained from the photographs, and hence the orbit of the meteor stream will be better known.

In the reduction of the measures of the photogrophic plates for the great Cape Photographic Durchmusterung, Kapteyn discovered another 'runaway' star with a proper motion of 8.71 seconds a year, which is much greater than that of the celebrated 1830 Groombridge, and is at present the largest proper motion of any known star.

There are very few departments of astronomy where photography has not taken a prominent, if not a commanding posi-

tion. It is probable, however, that it will never take the place of the micrometer in the observation of the close double stars, and in this direction, the micrometer of Burnham will perhaps never be displaced. The photography of the surface features of the planets is in an almost hopeless condition at present, yet much can be expected in this direction when an increased sensitiveness of the plates has been secured.

Photography has shown its value in the determination of stellar parallax, and probably hereafter it will essentially take the place of the micrometer in this direction.

This is not the place to go into a discussion of the relative values of the refractor and reflector for photographic work. Where accurate measurement is to be considered, the refractor is doubtless better than the reflector. If, however, the main object is a great quantity of light, such as is required for the photography of the nebulæ, the large aperture of the reflecting telescope of short focus makes it, perhaps, the best form of instrument (though it is very much hampered by its small field). This has been shown to be true by Common and Roberts. Since in the reflector the light does not pass through the glass, it is possible to use very large apertures without any additional loss of light through absorption, as would necessarily occur if it passed through a large object glass.

Mr. Ritchey, of the Yerkes Observatory, is making a large glass speculum, five feet in diameter and twenty-five feet focus, which, when finished, will be one of the most powerful instruments for photographic and spectroscopic work yet made, and which deserves a more extended notice than my limited time will permit me to give it here. With this instrument, and Mr. Ritchey's skill in photographic work, results of high importance will be obtained.

Through the intelligent generosity of Miss Catherine W. Bruce, of New York city, astronomical photography has been placed on a firmer basis than it ever was before. Her gifts have been made to all departments of astronomy, and it would take considerable space to properly enumerate them all. Perhaps the most important of these are the ones that bear directly upon astronomical photography.

The first of these gifts was the great 24-inch photographic doublet, by the late Alvan Clark, presented to the Harvard College Observatory, and which is now doing such excellent work in Peru; the two 15-inch portrait lenses for Dr. Max Wolf, of Germany, and a 10-inch photographic doublet for the Yerkes Obser-

vatory. These instruments are the most powerful of their kind, and for certain classes of work are superior to any other form of telescope. The results of the splendid gifts of this lady must hereafter have the greatest influence upon the higher development of astronomical photography.

It is impossible within the limits of this address to give more than a general, and at best incomplete, sketch of the rise and progress of photography in the various lines of astronomical research. To those who have kept pace with these rapid strides in the last twenty years this brief history will seem imperfect, and perhaps of little interest. Many applications of the photographic art and many valuable results have necessarily been omitted. But few of the names of those prominently identified with this subject have been mentioned, and but little of their work even alluded to. A volume of no small dimensions would be necessary to give a complete history of the development of photography in the many directions in which it has been applied to astronomy. The time to do this has not yet come. Progress has been so rapid and far-reaching that its history, however complete and exhaustive, a year later requires to be re-written; and there is no reason for supposing that the end, or even the beginning of the end, has been reached. With new materials and new methods, and new workers who will profit by the experience and results gained by those who have in our time accomplished so much, we may expect for the new century far greater results than those briefly recorded here.

It would be difficult just here to predict the future of astronomical photography, though one can forsee something of the great results it must accomplish.

It will displace some of the visual work, but it is more likely to move along new lines—opening up new fields of research.

The older astronomy, so nobly represented by Simon Newcomb and a few others, will be strengthened at every point and will stand all the more sublime for the help it shall receive from photography.

YERKES OBSERVATORY.

OUTLINE OF THE HISTORY OF ASTRONOMY.

HERMAN S. DAVIS.

FOR POPULAR ASTRONOMY.

This outline is composed principally of the names of those astronomers who have been most instrumental in bringing the science of astronomy to its present stage of development; for

around the lives of such zealous workers cluster all the facts and fancies of this celestial science.

The trials of a Galileo; the triumphs of a Kepler; the patience of a Tycho; the griefs of an Hevelius; the martyrdom of a Bruno; the unhappy fate of an Hypatia—all go to show how real is the life of a scientist in whatever Age, and how much the progress of a science is due to individuals instead of chance. One is too apt in these days to accept a condition without inquiring into the growth of that condition. To set forth, therefore, a clear chronology of those who have devoted their lives to this ennobling science, as a guide to an extended study of the History of Astronomy is the object of this article for the readers of POPULAR ASTRONOMY.

I. MYTHICAL PERIOD.

"Astronomy is a science so ancient that we can hardly ascend to a period when it did not exist." It is in Asia, the seat of all the early inventions of mankind, that we discern the dawn of this sublime science. The annals of the Chinese contain the earliest records of celestial phenomena; but the Chaldean observations are more interesting to Europeans on account of their connection with modern astronomy.

Chaldæan, Babylonian. Chinese. Indian, Hindu.
Egyptian, Phœnician. The Druids.
Mexican, Aztec.

II. TRADITIONAL OR PHILOSOPHICAL PERIOD.

When the knowledge of astronomy was almost wholly among the Greek philosophers—when they had no true theories; no instruments of value; no precise observation; and only a superficial knowledge of the application of Geometry.

Thales	(Ionic School)	...546 B. C.
Anaximander		610...547
Anaximenes		530...480 ±
Pythagoras	(Pythagorean)	569...470
Anaxagoras		499...430 ±
Eudoxus		421...352 ±
Aristotle		384...322
Aristarchus		*fl* 270
Erathosthenes	(Alexandrian)	276...196

Minor philosophical astronomers: Meton, *et al.*

III. Historical Period.

When the progress of mathematics is remarkable: and astronomy is enriched by numerous discoveries and by written records.

Hipparchus	*fl* 150 B. C.
Ptolemy	*fl* 150 A. D.
Hypatia (first woman astron.)	370?...415
Capella	*fl* 470
Brahma-goupta	*fl* 527
Isidorus	570...636
Yhiang	...727

Minor astronomers before the fall of Alexandria.

Stationary or Arabic.

The Alexandrian School was destroyed by the Saracens under Amrou Abn Al Aas in 640 A. D. during the caliphate of Omar I. Astronomy had its rise among the Arabs under caliph Almansor in 762. This is a long and remarkable period which intervened between the scientific activity of ancient Greece and that of modern Europe. "While beneath the sign of the Cross the night of barbarism was settled down on the Western World; in the East, under the green standard of the Prophet, an original form of civilization had been developed, which not only preserved what had been won by the classical peoples, but even itself made no mean acquisitions in the sciences."

Al Mamum	786...833	Alhazen	...1038
Albategnius	877?...929	Albiruni	*fl* 1000
Al Sufi	903...986	Aben-ezra	1119...1174
Abul Wefa	939.. 998	Averroes	1126...1198
Ebn Junis	...1008		

Transitional. *The Renaissance.*

Europe was emerging from her darkness. The revival of practical astronomy may be dated from the founding of the first Observatory in Europe, erected at Nuremburg in 1472 by Bernard Walther.

[Roger Bacon]	1214...1292	Regiomontanus	1436...1476
Arybhatta	*fl* 1322	Bernard Walther	1430...1504
Ulug Beigh	1394...1459	Leonardo da Vinci	1452...1519
Purbach	1423...1461	John Werner	1468...1528

Instrumental.

The whole science was revolutionized by the introduction of the system of Copernicus and by the invention and use of the telescope.

Copernicus	1472...1543	John Hevelius	1611...1688
Tycho Brahe	1546...1601	Huygens	1629...1695
Kepler	1571...1630	G. D. Cassini	1625...1712
Galileo	1564...1642	Flamsteed	1646...1719

PRECISE OBSERVATIONAL AND MATHEMATICAL.

"Abstruse mathematical theories . . . . during the eighteenth century constitute the sum and substance of astronomy and their fundamental importance can never be diminished and should never be ignored." A period distinguished by the effort to extend, correct and methodise the results previously secured.

The application of glasses to graduated instruments, which has contributed exceedingly to the progress of practical astronomy, remained sterile in the hands of Morin who conceived the first idea of it in 1634. It was generally adopted only towards the beginning of the eighteenth century and it was not until then that the most delicate researches began.

NEWTON	1642...1727	Le Gentil	1725...1792
Halley	1656...1742	Lalande,	1732...1807
Bradley	1692...1762	Maskelyne	1732...1811
La Caille	1713...1762	Lagrange	1736...1813

PHYSICAL; *Spectroscopic and Photographic.*

The principal subjects of investigation are the physical characteristics of the solar system and universal gravitation; numerous photographic records and discoveries are made of solar, planetary, stellar and nebular features.

William Herschel,	1738...1822	Brinkley	1763...1835
Delambre	1749...1822	Bessel	1784...1846
Piazzi	1746...1826	Gauss	1777...1855
Fraunhofer	1787...1826	W. C. Bond,	1789...1859
La Place	1749...1827	Otto Struve,	1793...1864
Le Gendre	1752...1833	Argelander	1799...1875

Le Verrier, Adams, Secchi, Watson, Draper, Clark, Proctor, Maria Mitchel, Gould; minor astronomers, and those now living.

LIST OF HISTORIES TO READ.

Jo. Friderici Weidleri *Historia Astronomiae* sive de ortu et progressu astronomiae. Vitembergae, 1741.

Bailly's *Historie de l' Astronomie* in four volumes, continued in a fifth by Voiron. Paris, 1775-1810.

Narrien's Historical Account of the *Origin and Progress of Astronomy*. London, 1850.

Maedler's *Geschichte der Himmelskunde* von der ältesten bis auf die neueste Zeit. Braunschweig, 1873.

Rudolf Wolf's *Geschichte der Astronomie*. München, 1877.

Hoefer's *Histoire de l'Astronomie* depuis ses origines jusqu' à nos jours. Paris, 1873.

Perhaps the best *series* of books (in the English language) for a connected survey of the history of astronomy and intimately related subjects is the following:

Draper's History of the *Intellectual Development of Europe*. New York, 1876.

Lewis's Historical Survey of the *Astronomy of the Ancients*. London, 1862.

Whewell's *History of the Inductive Sciences* from the earliest to the present time. New York, 1888.

Grant's *History of Physical Astronomy*. London, 1856.

Clerke's *Popular History of Astronomy During the Nineteenth Century*. London, 1893.

COLUMBIA UNIVERSITY. New York City.
August, 1898.

NOTE ON A PRACTICAL PROBLEM FOR BEGINNERS IN COMETARY COMPUTATION.

S. C. CHANDLER.

FOR POPULAR ASTRONOMY.

The number of known comets of short period is now so considerable that the problem frequently arises to compute, from the first known observation of any of them on a recognized return, the time of perihelion passage; from which, and the other elements assumed as known according to previous returns, a correct ephemeris for the appearance may be calculated. The practised computer of course needs no assistance in so simple a matter, but the student not yet entirely familiar with the subject may find the following note of some use, especially as the formulas for the case in question are not directly provided in the text-books.

Various processes may be adopted for the purpose in hand, but I have here arranged formulas which appear to me to be most convenient and direct, especially adapted for logarithmic computation.

Let t be the time of the observation; λ and β the latitude and longitude computed from the observed α and δ of the comet; and $\odot$ and R the coödinates of the Sun for the same instant. Assuming the position and form of the orbit as known, we have Ω, i, ω, e and a, taken from the elements at the previous return. All the above quantities are to be referred to the ecliptic and equinox of the same date.

First compute auxiliaries as follows:—

$$f \sin F = \sin(\lambda - \Omega) \quad ; \quad g \sin G = f \sin(F - \beta)$$
$$f \cos F = \cot i \quad ; \quad g \cos G = \cos\beta \cos(\lambda - \Omega)$$

$$h = \frac{\sin\beta \sin(\odot - \Omega)}{\sin i}$$

then we find

$$\tan(v + \omega) = \frac{h}{g \sin(\odot - \Omega - G)}$$

$$r = \frac{R\,h}{g \sin G \sin(v + \omega)}$$

the sign of $\sin(v + \omega)$ is the same as that of $\sin\beta$, which determines the quadrant for $v + \omega$.

By means of these values of v and r the time of perihelion passage, T, may then be directly found by means of the known simple elliptical relations. Thus, for example, we can find two independent values of E through,

$$\tan\frac{1}{2}E = \sqrt{\frac{1-e}{1+e}}\tan\frac{1}{2}v \quad ; \quad \cos E = \frac{a - r}{ae}$$

and thence two independent values of T by

$$T = t - \frac{E - e\sin E}{\mu}$$

which would precisely agree if the assumed elements and the observed α and δ were exact. In general this will not be the case. We can adopt the mean of the two; or, if an accurate accordance with both observed coördinates is desired, another element may be assumed as unknown; for instance, the mean distance, a, which is to be found by

$$a = \frac{r}{1 - e\cos E}$$

T being taken as coming through $\tan\frac{1}{2}E$.

A numerical example seems unnecessary, but, to blaze the way for the tyro, one from actual practice may be briefly indicated. From early observations of comet *a* 1898, the return of Winnecke's comet, the following observed place was deduced through comparison with an accurate ephemeris:

$t = 1898$ Jan. 3.000 Gr. M. T., $\alpha = 15^h\,22^m\,18^s.45$, $\delta = -4°\,11'\,36''.8$

which is corrected for parallax and aberration and referred to the mean equinox 1898.0.

From von Hærdtl's elements of the comet at its previous returns, reduced to the equinox 1898.0, we have (see *Astronomical Journal* No. 424, p. 127).

$\omega = 173°\ 21'\ 10''.0$ $\quad \log e = 9.854161$
$\Omega = 100\ \ 51\ \ 45\ .5$ $\quad \log a = 0.510521$
$i = 16\ \ 59\ \ 34\ .0$ $\quad \mu = 608''.45$

From the almanac, and the above α and δ,

$\odot = 283°\ 12'\ 4''.3$ $\quad \lambda = 229°\ 16'\ 56''.4$
$\log R = 9.9926722$ $\quad \beta = +\ 13\ \ 51\ \ 31\ .8$

Then from the above formulas

$\log f = 0.5269509$ $\quad F = 13°\ 27'\ 52''.66$
$\log g = 9.7808716$ $\quad G = 182\ \ 11\ \ 50\ .57$
$\log h = n\ 8.5243128$

whence

$v = -80°\ 48'\ 20''.8$ $\quad \log r = 0.1528666$

which give respectively two values of E

$E = -38°\ 17'\ 18''$; or $\quad E = -38°\ 16'\ 30''$

whence

$T = 1898$ Mar. 20.403, or 1898 Mar. 20.369
The mean being Mar. 20.386

or, we can find with the first value of E, and $\log r$,

$$\log a = 0.510423$$

and this with $T = 1898$ Mar. 20.403 Gr. M. T. and the assumed values of ω, Ω, i and e, will satisfy the observed position exactly, in both coördinates.

YOUNG'S REVISED GENERAL ASTRONOMY.

W. W. PAYNE.

The revision of Young's General Astronomy has been in progress for more than a year past. All those who are acquainted with this standard text-book in general astronomy know that its first edition was issued ten years ago, a few months later in the year 1888 than the time of this year at which the revision appears. We were ourselves so much interested in the new book in September, 1888, that we sought of the publishers, (Messrs. Ginn & Co., Boston) a sufficient number of proof-sheets, as the book was passing through the press, to accommodate a college class of about twenty in the first term of that school year. In this way, we were greatly favored by the publishers, and it is almost needless to say that the students pursuing the study at that time were interested greatly in the novelty of a proof-sheet text, but even more in the real merit of a work in astronomy for text

and reference use without an equal in the English language. That book was not made in a month or a year. On the face of its 500 pages and more are plain evidences of scholarly work and thought that must have covered the best years of a busy life. The fruits of this masterful toil were well ripened ten years ago and the forecasts of what astronomy would be and do in ten years to come were then, in some ways, rather significantly foretold. This is why the book has stood so well during the last half decade, while science and scholarship have been severely critical and astonishingly progressive. The time that an edition of a good book will last is a fair indication of the progress of the branch in the science it represents. The *Almagest* of Ptolemy was authority in astronomy for 1400 years, not because it represented the best views of the scholars of this long period, but because the science had so little truth and life in itself that it could not grow rapidly. The best of the astronomies that were written between 1845 and 1860 have been useful only about 35 years, because of the more rapid growth of the science during that period. Now it appears that the best of books needs a revision in the very short period of ten years. At this rate of progress what are we to expect during the next quarter of a century? It is not safe to make any prediction.

It will certainly interest our readers to notice briefly the changes and additions which the author presents in the revision of his General Astronomy, for that ought to show how astronomy has grown during the time above specified. The Introduction is the same as in the first edition except the reference at the close is, to Magie's revised edition (1897) of Anthony and Brackett's text-book on Elementary Physics.

On page 6 the rule is added to reduce *radians* to seconds of arc. An important note is added on page 20 designed to explain the ordinary estimate of the size of the Sun and Moon, as "about a foot in diameter," the author suggesting that the estimate "probably rests upon a physiological fact." In *Comptes Rendus* de l' Académie des Sciences for 1898, May 9, occurs an article by E. D. Eginitis "On the Apparent Increase in Size of the Solar and Lunar Discs when near the Horizon." After stating the common theories that have been provided and the objections to each, this author says according to our observations the chief cause of these phenomena still remains unknown. A translation of the article is found in the *Observatory*, Sept. 1898, page 334.

The next point of interest that is new, is the addition of a number of exercises at the close of each chapter after the third.

On page 69 and on others following are found brief review exercises covering the preceding chapters. Though these exercises form only a small part of the text, teachers will use them with others which they suggest. Figure 39, page 75, is correctly projected in this revision; not so in the old text.

Paragraph 108, concerning the variation of latitude and the motion of the poles, is expanded to fill a page, as its importance deserves. It is one of the most notable of discoveries made in astronomy during the last decade. It was suspected in 1888 and later verified by a piece of brilliant mathematical work by Dr. C. S. Chandler, of Cambridge, Mass. The results of this work, with a cut illustrating the motion of pole, were published in this magazine in Nov. 1895, by Professor Eric Doolittle. Since, Albrecht has given attention to the problem and recently published his results with a diagram showing the path of the pole from 1890 to 1895. A copy of Albrecht's figure is presented in the exercises following chapter IV. On page 94 is found a new paragraph showing how to compute the time of the rising or setting of a star or the Moon. This well completes the topic under which it is found, viz.: the determination of the position of a heavenly body. Articles 146 and 147, describing the three ways of determining the form of the Earth, are much improved in the new book. Two paragraphs are added on page 110, which give clear descriptions of the forms of pendulum used in the Coast Survey service, for the purpose of determining the force of gravity at various points. It also appears on page 113 that the oblateness of Earth's form ranges between $\frac{1}{290}$ and $\frac{1}{300}$. Professor Harkness' value in his "adjusted" system of astronomical constants is given as a little less than $\frac{1}{300}$.

On pages 116 and 123 are two new paragraphs. The former defines gravity and tells how mass is measured. Though fuller and better than before, it might have been extended and illustrated a little more. The theme is difficult for good students to comprehend. The latter is the measurement of mass by means of inertia. That paragraph is excellent.

On page 134, under "Seasons," are two new illustrations showing the position of the pole at the solstice and at the equinox.

A list of twenty exercises follows Chapter VI. They are well chosen. The changes in the next chapter, which treats of the Moon, occur in the last three pages. In the measurement of lunar mountains a figure was given in the old edition which served its purpose well. We are sorry it is omitted in the revision. The

added paragraph, which fills a page nearly, and is meant to supplement the former text in the study of the lunar atmosphere, is a brief statement involving the principle of the kinetic theory of gases that has occupied the attention of physicists much in the last few years. This matter rightly claims attention in this connection, and it is quite fully presented. The chapters relating to the Sun have received full and careful attention, as might be expected; for if the author is partial to one branch of astronomy more than another, it seems to be that of the Sun.

On page 189 is found a fuller statement than before with illustrations regarding the position of the Sun's axis during the year. The paragraphs referring to the law of rotation of the Sun have been re-written in part, and the order of the matter somewhat rearranged advantageously. The reference to the discussion now going on in relation to the level of the nucleus of the sun-spot was expected. It is too early yet to say what will be the result of present investigation. In this connection is added a new paragraph on the radiation and temperature of sun-spots, and also another on the theory of sun-spots proposed by E. Oppolzer, of Vienna, in 1893, which is new. The main point in this theory is the supposition that currents rise from the polar regions of the Sun periodically, and drift slowly towards the equator, descend in the spot zones, becoming heated and "dried" as they descend, thus forming lower places in the photosphere which are filled with metallic vapors in a pure, gaseous condition. Several points in this new theory are helpful in explaining some things about the sun-spot spectrum. Spoerer's law of the sun-spot latitudes, and other observations not yet accounted for. The reason for the "periodical polar streams" is still to be explained. This law of the sun-spot latitudes which has recently been put forward by Spoerer, is doubtless one of the highest importance, for its explanation may so modify our theory of the constitution of the Sun as to be of great theoretical value. The fact observed about the sun-spot zones is the fact that a disturbance which produces the spots of a given sun-spot period, generally first manifests itself in two belts about 30° north and south of the Sun's equator. "These belts then draw in toward the equator, and the sun-spot maximum occurs when their latitude is about 16°," and the disturbance dies out about 8° or 10°, some twelve or fourteen years after it began. New zones of disturbance will appear two or three years before the end of the old ones, and so the possibly related activity between the old and the new goes on very curiously. The new figure showing Spoerer's curves of

sun-spot latitudes nicely illustrates these changes between 1855 and 1880, as compared with the curve of Wolfe's "relative numbers" for the same period.

There is so much more of interest in this review that we must say more about it at another time.

GRAPHICAL REPRESENTATION OF A COMET ORBIT.

GEORGE C. COMSTOCK.

FOR POPULAR ASTRONOMY.

It is always a matter of interest and sometimes one of importance to learn the general characteristics of a comet's motion and the relation of its orbit to that of the earth as soon as possible after the comet's discovery. The first elements of the orbit are usually derived and published by the computers within a few days following the discovery, but of themselves these convey little information to the uninitiated until a graphical representation of them is made and I have been accustomed for some years to make such a representation by the following method which has proved very convenient and quite accurate enough for the purpose in hand.

As the method is best illustrated by an example I take the following provisional elements of the orbit of Comet *h*, 1898 (Perrine) and commence the construction of the corresponding orbit by drawing a circle to represent the orbit of the earth, with the sun, *S*, at its center and the radius *SV* representing the direction from the sun to the vernal equinox, *V*. The earth is at *V* on Sept. 22 and its subsequent positions at ten day intervals are shown by laying off successive equal arcs of 10° from *V*.

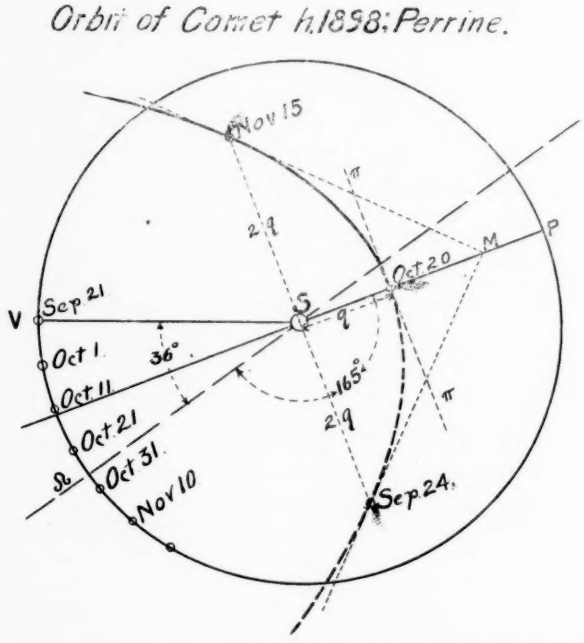
ELEMENTS OF COMET *h*, 1898.

$T = 1898$ Oct. 20
$\omega = 165°\ 17'$
$\Omega = 36\ \ 5$
$i = 29\ \ 12$
$q = 0.3842$

The element Ω, which is called the longitude of the node, shows that the plane in which the comet orbit lies intersects the plane of the earth's orbit along a line $S\Omega$ which makes an angle of 36° with *SV* and the element i measures the angle, 29°, between these two planes. We shall for the present take no account of this latter element but construct the comet orbit in the plane of the

paper and subsequently imagine it to be revolved about the line $S\Omega$ through an angle of 29°.

The element ω is the angle at the sun between the line $S\Omega$ and the line SP drawn from the sun to the comet's perihelion, *i. e.* that part of the orbit nearest the sun, and it is to be reckoned in the direction of the comet's motion along the orbit. This precept for the direction in which ω is to be measured is practically equivalent to saying that it is to be set off in the direction of the earth's motion whenever the angle i is less than 90° and in the opposite direction when i is greater than 90°. In the present case we lay off the angle $\Omega SP = 165°$ and also lay off on SP a distance q equal to 0.38 of the radius of the Earth's orbit; since the element q represents the distance of the comet's perihelion from the sun expressed as a frational part of the Earth's distance.



Since the orbit of a comet rarely differs much from a parabola having the sun at its focus, we may complete our diagram by drawing such a parabola having its vertex at the point determined by the distance q and its axis coincident with the line PS. If a few points along this parabola are determined the curve it-

self may be drawn through them freehand or by the use of an engineer's "irregular curve," and we may determine two of these points by drawing through S a line at right angles to SP and laying off on this line, on either side of S, a distance equal to $2q$. If the points thus determined are connected with the point M, situated on SP at a distance $2q$ from S, the connecting lines will be tangents to the parabola and a line, $\pi\pi$, drawn through the perihelion perpendicular to SP will also be a tangent to the orbit. These three points and three tangents will usually suffice for the construction of the orbit with all needful precision.

The element T shows that the comet passes through its perihelion point on Oct. 20, 1898, and this date may be entered at once on the sketch opposite the perihelion. The dates at which the comet passes the other points of its orbit at which tangents have been drawn are readily found from some principles of theoretical astronomy. If the comet's perihelion distance from the sun were equal to the earth's distance it would require 110 days for the comet to move over the arc included between perihelion and either of the points in question, but since the comet is much nearer the sun than is the earth it moves more rapidly and the time required is found by multiplying 110 by q times the square root of q. In algebraic notation

$$110\, q\sqrt{q} = 110 \times 0.3842 \times \sqrt{0.3842} = 26 \text{ days}$$

which added to and subtracted from Oct. 20 gives Sept. 24 and Nov. 15 as the respective dates for the two points in question. If the position of the comet at other dates is required these may be set off upon the orbit by estimation remembering that the comet moves the more rapidly the nearer it is to perihelion.

It must be borne in mind that the diagram as thus constructed does not show correctly the relative positions of the comet, earth and sun but these positions will be shown aright if the plane of the comet's orbit be now revolved about the line $S\Omega$ through an angle of 29° so that the position of the comet on Nov. 15 shall fall on the north side of the ecliptic (above the plane of the paper). The point at which the comet passes through the plane of the earth's orbit lies in the line $S\Omega$ and reckoning from this point that part of the comet orbit which lies south of (below) the ecliptic is represented by a broken line.

The general circumstances of the comet's motion may now be read from the diagram without difficulty. In the latter part of October it will be in superior conjunction with the sun and invisible on that account although its real brilliancy, which increases

rapidly during the first half of October as the comet approaches the Sun, will be a maximum about the time of conjunction. In September and the early part of October the comet will be visible in the morning hours since its longitude as seen from the earth is then less than the sun's longitude (the comet falls to the right of the sun in the diagram) but after conjunction with the Sun, about Oct. 24, it will emerge from the sun's rays upon the other side and be visible during November in the evening hours. At the time of conjunction with the sun the comet will be quite near the ecliptic and therefore nearly in line with the sun and as it is then moving northward at the time of its reappearance it will stand further north in the heavens than does the sun but it will probably not come far north of the celestial equator if indeed it reaches that limit.

One other suggestion of the diagram is worth noting. Since the tails of comets point away from the sun it is apparent that any tail which the present comet may develop will be very much fore-shortened as seen from the earth and can not, therefore, be expected to appear very long.

WASHBURN OBSERVATORY,
Sept. 24, 1898.

PLANET NOTES FOR OCTOBER.

H. C. WILSON.

Mercury is morning planet, but too close to the Sun to be seen with the naked eye. On the 19th, in the forenoon, Mercury will be at superior conjunction with the Sun, passing about 40° to the north of the Sun's center projected.

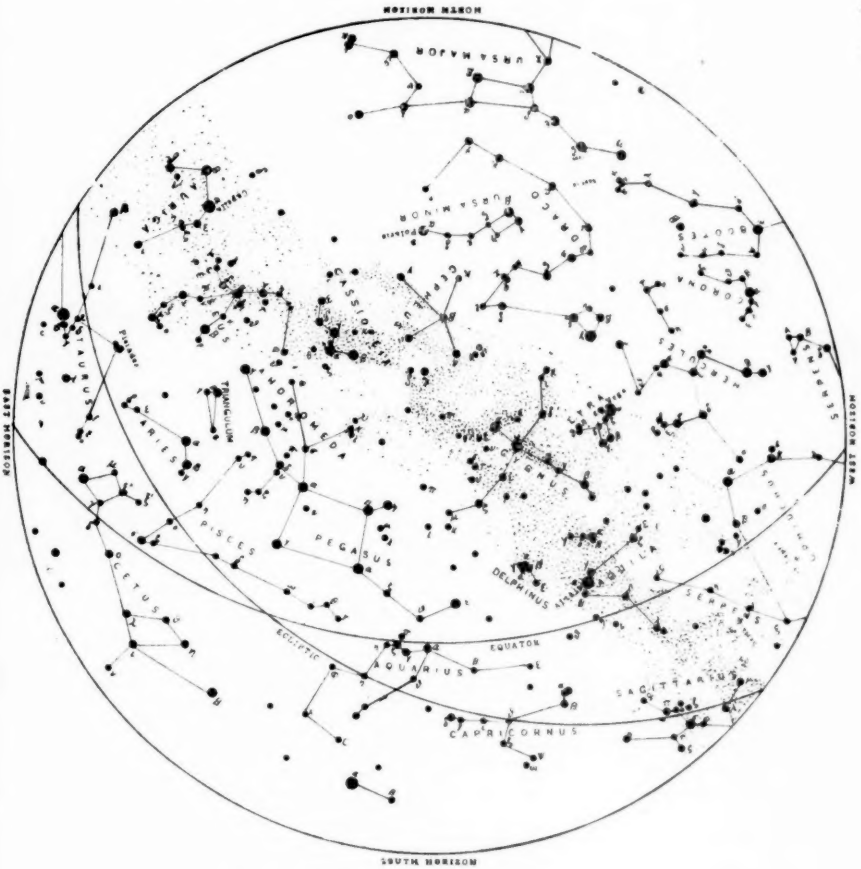
Venus, having passed greatest eastern elongation in September, is now moving slowly in toward the line joining Earth and Sun. She will increase in brilliancy until near the end of this month but her low altitude will prevent this increase from being noticeable in our latitude. In southern countries, observers will have good opportunities for the study of the planet during this month. The phase of Venus is now crescent and will soon decrease rapidly. Venus and the Moon will be in conjunction about noon on the 18th, the planet being two degrees south of the Moon.

Mars is visible during the latter half of the night, being at quadrature, 90° west from the Sun, on the 17th. Mars is near the center of the constellation Gemini and will move eastward to the middle of Cancer during the month. The Moon will pass Mars, Oct. 7.

Jupiter will be in conjunction with the Sun on the 13th and will be hidden by the solar glare during the whole month.

Saturn is too low in the southwest for observation in the evening but something of it may be seen in the early twilight. Saturn and Venus will be in conjunction on the morning of Oct. 22, Saturn being then six and three-quarters degrees north of Venus.

Uranus **is in the same part of the heavens with Saturn and not favorably situated for observation. Uranus and Venus will be in conjunction Oct. 10, Venus being about five degrees south of Uranus.**



THE CONSTELLATIONS AT 9 P. M., OCTOBER 1, 1898.

Neptune may be observed with telescope after midnight. This planet is to be found in the eastern portion of Taurus, a little way east of the star Zeta, in the tip of one of the horns of The Bull.

The Sun has been considerably disturbed during the past month. An enormous spot, followed by a train of smaller ones, was near the center of the solar disc Sept. 9.

The Moon.

		Phases.	Rises. (Central Standard time at Northfield; Local Time 13m less.)	Sets.
			h m	h m
Oct.	7	Last Quarter	10 59 P. M.	2 22 P. M.
	15	New Moon	6 46 A. M.	5 8 "
	22	First Quarter	1 48 P. M.	11 54 "
	29	Full Moon	4 49 P. M.	8 15 A. M.

Occultations Visible at Washington.

Date 1898.	Star's Name.	Magnitude.	IMMERSION. Washington M. T.	IMMERSION. Angle from N pt.	EMERSION. Washington M. T.	EMERSION. Angle from N pt.	Duration.
			h m	°	h m	°	h m
Oct. 3	33 Tauri†	6.3	7 27	83	8 18	247	0 51
3	B.A.C. 1238	6.3	9 19	149	9 34	177	0 15
8	B.A.C. 2810	7.0	12 15	103	13 14	279	0 59
8	δ^2 Cancri	6 0	12 51	122	13 49	261	0 58
10	π Leonis†	5.0	13 40	134	14 32	265	0 52
17	42 Libræ*	5.7	7 39	71	8 29	294	0 50
24	$\varkappa$ Aquarii	5.2	12 23	17	13 10	282	0 47
25	$\varkappa$ Piscium	4.7	11 27	57	12 39	239	1 12
25	9 Piscium	6 6	11 34	93	12 32	203	0 58
29	47 Arietis	6.0	16 7	152	16 29	189	0 22
30	B.A C. 1170	6.3	13 40	37	14 47	301	1 7
30	33 Tauri	6.3	18 42	135	19 24	224	0 42

New Planetoid (DQ)—A cablegram from Dr. Kreutz of the Astronomical Centralstelle, Kiel, communicated to American astronomers by Mr. John Ritchie, on Sept. 5, announces the discovery of a planet, (*DQ*) with a remarkable orbit, of which the perihelion lies within the orbit of Mars. The element Mu, or the average daily motion is 2000″.

EPHEMERIS.

Gr. Midnight. 1898	R. A. h m s	Decl. ° ′	Light.
Sept. 6	20 49 4	− 6 19	1.00
10	20 44 40	− 6 20	
14	20 41 4	− 6 21	
18	20 38 24	− 6 21	0.98

The ephemeris was computed from observations of August 14, 23 and 31. The asteroid was discovered by Witt of Berlin on August 13 when its magnitude was 11.0. It was announced in *Astronomische Nachrichten* No. 3512, where attention was called to its remarkable motion.

Elements of the Orbit of Planetoid 1898 DQ.—In *Astronomische Nachrichten*, No. 3517, Dr. Berberich gives the following elements of planet 1898 *DQ* calculated from observations by Witt at Urania August 14, 23 and 31. A compaiison with 40 observations made at various Observatories during the same interval of time shows that the elements are very nearly correct.

ELEMENTS.

Epoch 1898, Aug. 31.5 Berlin mean time.

Mean anomaly	$M =$	220°	14′	3″.7
Distance node to perihelion	$\omega =$	178	28	26 .2
Longitude of node	$\Omega =$	303	48	53 .0
Inclination	$i =$	11	6	57 .1

Angle of eccentricity	$\varphi = 13\ 13\ 3\ .8$
Eccentricity	$e = 0.22865$
Mean daily motion	$\mu = 2010''.131$
Semi-major axis	$a = 1.46057$
Period	$P = 644.7$ days.

The accompanying diagram will show the relation of the orbit of this new planet to those of the Earth, Mars and Jupiter. It will be seen that the major axis of the orbit is less than that of Mars, although at aphelion the asteroid is outside of Mars' orbit. At perihelion it approaches quite near the Earth's orbit, the least distance being only about 13,000,000 miles. At a favorable opposition therefore this asteroid will afford a splendid opportunity for determining its parallax and thus the dimensions of the solar system. Its equatorial horizontal parallax may reach as high a value as one minute of arc.

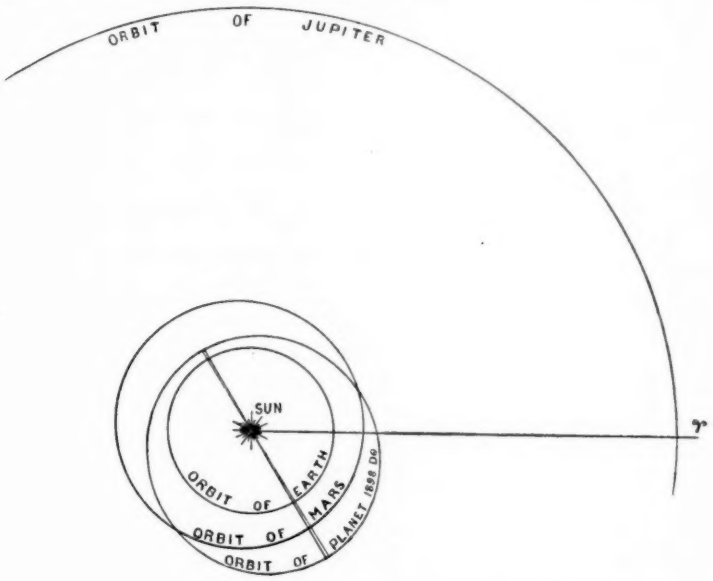


DIAGRAM SHOWING THE ORBIT OF THE NEW PLANET, 1898 DQ.

At this apposition the planet was near aphelion, so distant from the Earth that its magnitude was only 11.0, but when its perihelion and opposition occur together it should be of about the sixth magnitude.

The following ephemeris for the first days of October will show where the asteroid now is.

EPHEMERIS.

Berlin Midnight.	α			δ			log r	log Δ
	h	m	s	°	′	″		
Sept. 30	20	35	22.56	− 6	16	25.0	0.2271	9.9717
Oct. 1		35	26.92	6	15	32.5		
2		35	34.10	6	14	35.0		
3		35	44.06	6	13	32.5		
4	20	35	56.75	− 6	12	24.8	0.2249	9.9846

VARIABLE STARS.

J. A. PARKHURST.

Minima of the Variable Stars of the Algol Type.

[Given to the nearest hour in Greenwich Mean Time.]

1898.

U CEPHEI.

	d	h
Nov.	4	15
	9	14
	14	14
	19	14
	24	13
	29	13

λ TAURI.

	d	h
Nov.	10	23
	14	22
	18	20
	22	19
	26	18
	30	17

S CANCRI.

	d	h
Nov.	7	13
	26	12

Y CYGNI.

Even min.

	d	h
Nov.	1	8

Odd min.

Nov.	2	11

ALGOL.

	d	h
Nov.	5	23
	8	20
	11	17
	14	13
	17	10
	20	7
	28	21

R CANIS MAJORIS.

Every 8th min.

$P = 1^d\ 3^h.3$

	d	h
Nov.	4	3
	13	5
	22	7

S VELORUM.

	d	h
Nov.	5	21
	11	20
	17	18
	23	16
	29	15

W DELPHINI.

	d	h
Nov.	8	18
	13	13
	18	9

Maxima and Minima of Long Period Variables.

1898 December.

MAXIMA.

		m	day
267	V Andromedae	8	34
419	U Andromedae	9	25:
466	U Piscium	9.5	7
976	T Arietis	8	15
1761	R Orionis	9	2
2258	V Aurigae	9	13
2625	V Geminorum	8.5	30
2815	U Geminorum	9.3	13:
2946	R Cancri	7	15
2976	V Cancri	7	12
4994	S Leonis	9.5	15
4521	R Virginis	7	23
4573	RU Virginis	8	37:
5037	RR Virginis	11	20
5566	RU Librae	8.5	16
5617	U Librae	9	13
5795	W Scorpii	10.5	2
5889	U Herculis	7	5
6132	R Ophiuchi	7.5	18
6331	RU Scorpii	9.5	15:
6905	R Sagittarii	7.5	15
6921	S Sagittarii	9.5	7
7450	V Aquarii	8	16
7609	T Cephei	6	23
7783	RU Cygni	7.5	28
8230	S Aquarii	8.5	36
8324	V Cassiopeae	7.5	4
8597	V Ceti	9	13

MINIMA.

			m	day
114	S Ceti		12	2
715	S Arietis		14	13:
1582	S Tauri		13	30
1635	R Reticuli	<	13	—
1717	V Tauri	<	13	40
1894	T Columbae		11	—
1944	S Orionis		12	15
1981	S Camelopardalis		11	20
2691	T Canis minoris	<	13	—
3170	S Hydrae	<	12	—
3186	T Cancri		10	24
4260	W Centauri		13	—
4377	T Virginis		12	—
5157	S Bootis		12.5	30
5190	R Camelopardalis		12.5	27:
5494	S Librae	<	13	—
5501	S Serpentis		12.5	—
5583	X Librae		14	5
5593	W Librae	<	14	—
5644	Z Librae	<	13	—
6943	T Sagittae		9.5	18:
7077	T Pavonis		12	—
7085	RT Cygni		10.5	7
7242	S Aquilae		11	33
7252	W Capricorni	<	14	36:
7455	U Capricorni	<	13	—
7456	RR Cygni		9.5	—
7468	T Aquarii		12.5	10
7733	Y Capricorni		14	—

The minima of Y Cygni are still visible only in European longitudes. The first minimum of each class is given. The others follow every third evening about five minutes earlier.

MINIMUM MAGNITUDE OF 7085 RT CYGNI. This is given in the above ephemeris as 10.5, but it will probably be at least one magnitude fainter. The magnitude at the minimum 1894 Oct. 15 was stated to be 10.0 by Professors Gruss and Laska of Prague, but the same minimum was observed photometrically by Mr. Henry M. Parkhurst as 12.4 on the photometric scale, corresponding to about 11.8 on the DM scale extended. I have observed the following minima, the epoch being counted from the elements of the Third Catalogue.

Date.	Epoch.	Mag.
1895 Oct. 11,	16 — —	11.9
1896 Oct. 26,	18 — —	11.7
1897 May 9,	19 — —	12.2
1897 Nov. 21,	20 — —	12.5
1898 May 23,	21 — —	11.7

The mean of the five is 12.0 magnitude, agreeing well with the mean of three minima observed by Mr. H. M. Parkhurst, 12.6, on the photometric scale.

VARIABLE STAR WORK AT THE GERMAN OBSERVATORIES. The last number of the *Vierteljahrsschrift*, Vol. 33, part 2, contains the annual reports of most of the German Observatories. From these reports the following items are taken.

BAMBERG. The director, Dr. Ernst Hartwig, reports the use of a Zöllner photometer for determining the magnitudes of comparison stars for variables. Supplied with a small objective, this instrument was used by Dr. Eberhard to observe the maximum of Mira, which he fixed at 1897 Nov. 24. Dr. Eberhard also observed the short-period variables β Lyræ, δ Cephei, η Aquilæ and the two new variables of this class, SU Cygni and U Vulpeculæ, which were discovered at Potsdam by Professors Müller and Kempf. With the 6-inch comet seeker 524 observations of variables were secured, besides 74 of SS Cygni, (maxima 1897 Aug. 10, Oct. 2, Dec. 2, 1898 Jan. 21, March 24, May 22) and 147 observations of Z Herculis.

MUNICH. Dr. W. Villiger found that Nova Aurigæ declined in brightness about one magnitude during 1897. Dec. 21 it was estimated as 12.3.

POTSDAM. Professors Müller and Kempf report in regard to their two new short period variables. U Vulpeculæ (BD. + 20°,4200, position for 1900: R. A. $19^h\ 32^m\ 15^s$, Decl. + 20° 6′.6) varies between 6.95 and 7.61 magnitude, with a period of 8.0 days (Dr. Hartwig found 7.97 days). The light curve is symmetrical, the increase and decrease occupying the same interval of time. SU Cygni (BD. + 28°,3460, position for 1900: R. A. $19^h\ 40^m\ 49^s$, Decl. + 29° 1′.2) varies from 6.57 to 7.38 magnitude with a period of 3.844 days (period confirmed by Hartwig). The increase in light requires about one-third the time taken by the decrease, resembling the light curve of δ Cephei.

UTRECHT. The director, Dr. Oudemans, reports the following observations:

Mira.....60,	ε Aurigæ.....21,
δ Cephei.....72,	ρ Persei.....22,
η Aquilæ.....44,	β Lyræ.....60,
Algol in full light...10,	Algol, 6 minima...87.

VIENNA. (Von Kuffner Observatory). Dr. L. De Ball describes an unusual method of determining the photographic brightness of variables. Finding that

the usual method, that of measuring the diameters of the focal images, failed to give good results, he tried the experiment of photographing the stars a little out of focus, and determining the magnitudes by comparing the blackness of the small disks thus formed. It was found that the probable error of comparison with a standard scale of blackness, was only 0.04 magnitude. The results of this work will be published under the title "Ueber die Bestimmung von Sternhelligkeiten aus extrafocallen photographischen Aufnahmen."

OLD THEORY OF STELLAR VARIABILITY.

The following extract from a letter written by Sir John Herschell to the editor of the *Astronomische Nachrichten* in 1839, published in Vol. XVI, page 187, is interesting on account of its *novelty*:

SLOUGH, Jan. 19, 1839.

"Being on the subject of the brightness of the stars, I should be very glad to see the attention of astronomers recalled to the subject of estimations by the naked eye, after the manner of my Father's catalogues of comparative brightness, but without confining the comparisons to separate constellations, as I am convinced that not only many more periodical stars will thereby be discovered, but that changes not periodical will be found to prevail to a very much greater extent than is now supposed, and which I would suggest may be accounted for by superadding to *Olber's* idea of imperfect transparency in the celestial spaces, that of inequality in the degree of opacity of different regions, and of movements going on in the opake matter whatever it be. In short by supposing the existence of some sort of cosmical *cloudiness* subject to internal movements depending on causes of which we are ignorant. Of the nature of these super-atmospheric clouds of course no conjecture can yet be formed, but some argument for their being of a material nature *may* be drawn from the strange observation of Ptolemy that Sirius was in his time one of the 6 red stars, classing it with Arcturus, Aldeberan, Pollux, Antares and Orionis by the common Epithet *ὑπόκιρρος*. It seems much more likely that a red color should be the effect of a medium interfering than that in the short space of 2000 years so vast a body should have actually undergone such a material change in its physical condition."

COMET NOTES.

New Comet Perrine, *h* 1898.—A telegram received Sept. 14 announced the discovery of a faint comet on Sept. 13 by Pechule of Copenhagen. This however turns out to be Wolf's periodic comet, which astronomers have been observing for three months past.

A genuine discovery was made on the morning of September 13 by C. D. Perrine at Lick Observatory. Elements and ephemeris of the comet by the discoverer were received by telegram Sept. 15 and later by letter. The comet is a telescopic one at present, but according to the elements will increase rapidly in brightness. Its position will, however, become less favorable for observation, the increased brightness being lost in the glare of the Sun, as it approaches perihelion.

Elements and Ephemeris of Comet *h* 1898 (Perrine.)—From the Mt. Hamilton observations of September 12th, 13th and 14th, we have obtained the following elements of the orbit of comet *h*, 1898:

$$\begin{aligned} T &= \text{Gr. M. T. 1898 Oct. } 20.0168 \\ \omega &= 165^\circ\ 16'\ 48'' \\ \Omega &= 36\ \ 5\ \ 29 \\ i &= 29\ \ 12\ \ 14 \end{aligned}$$ Ecliptic and mean equinox of 1898.0

$$\log q = 9.58456.$$

RESIDUALS FOR THE MIDDLE PLACE (O—C).

$$\Delta\lambda \cos\beta = +3'', \quad \Delta\beta = -1''.$$

CONSTANTS FOR THE EQUATOR, 1898.0.

$$\begin{aligned} x &= r\,[9.98128]\ \sin(287^\circ\ 44'\ 59'' + v) \\ y &= r\,[9.84825]\ \sin(215\ \ 18\ \ 50 + v) \\ z &= r\,[9.88374]\ \sin(183\ \ 7\ \ 23 + v) \end{aligned}$$

EPHEMERIS FOR GREENWICH MEAN MIDNIGHT.

	α h m s	δ ° ′	log Δ	Br.
Sept. 18.5	10 9 37	+ 27 59.4	0.1704	1.39
22.5	10 35 13	+ 25 8.4	0.1565	1.79
26.5	11 1 19	+ 21 45.2	0.1451	2.32
30.5	11 27 43	+ 17 49.0	0.1368	3.03

Brightness at discovery = 1.0.

The head of the comet is about 5′ in diameter and has a bright central condensation, but no stellar nucleus. A faint narrow tail can be traced for nearly a quarter of a degree in position angle 307°.

In brightness the comet is about equal to an 8th magnitude star.

C. D. PERRINE and R. G. AITKEN.

Lick Observatory, University of California,
Sept. 15, 1898.

Ephemeris of Comet 1898 I (Perrine).

[From *Astronomische Nachrichten*, No. 3510.]

1898	α app. h m s	δ app. ° ′	log r	log Δ	Brightness.
Oct. 1	6 31 33	+ 50 30.4	0.4753	0.4419	0.044
3	30 33	50 29.4			
5	29 24	50 28.4			
7	28 5	50 27.3			
9	26 37	50 26.1	0.4878	0.4362	0.043
11	24 59	50 24.8			
13	23 12	50 23.4			
15	21 15	50 21.7			
17	19 9	50 19.8	0.4999	0.4308	0.042
19	16 53	50 17.4			
21	14 29	50 14.6			
23	11 56	50 11.3			
25	9 14	50 7.6	0.5115	0.4264	0.040
27	6 24	50 3.3			
29	3 26	49 58.2			
31	6 0 20	49 52.5			
Nov. 2	5 57 8	49 46.0	0.5228	0.4234	0.039
4	53 49	49 38.7			
6	50 23	49 30.7			
8	46 52	49 21.8			
10	43 17	49 12.0	0.5338	0.4226	0.037
12	39 38	49 1.3			
14	35 56	48 49.5			
16	32 11	48 36.6			
18	5 28 22	+ 48 22.7	0.5444	0.4247	0.036

Ephemeris of Wolf's Comet 1898.

[From *Astronomische Nachrichten*, No. 3518.]

1898.	α	δ	log r	log Δ	Ab.-Time.	Brightness.
	h m s	° ′			m s	
Oct. 1	6 39 28	+ 3 33.2	0.2622	0.1928	12 56	2.65
2	40 50	3 14.2				
3	42 11	2 55.0	0.2644	0.1904	12 52	2.65
4	43 30	2 35.8				
5	44 47	2 16.6	0.2666	0.1880	12 48	2.65
6	46 2	1 57.3				
7	47 15	1 37.9	0.2688	0.1856	12 43	2.66
8	48 27	1 18.4				
9	49 37	0 58.9	0.2710	0.1832	12 39	2.66
10	50 45	0 39.4				
11	51 51	0 19.9	0.2733	0.1809	12 35	2.66
12	52 54	+ 0 0.3				
13	53 55	− 0 19.3	0.2756	0.1786	12 31	2.66
14	54 55	0 38.9				
15	55 54	0 58.6	0.2779	0.1763	12 27	2.66
16	56 50	1 18.2				
17	57 44	1 37.9	0.2801	0.1741	12 23	2.66
18	58 35	1 57.6				
19	6 59 25	2 17.3	0.2824	0.1718	12 19	2.66
20	7 0 13	2 36.9				
21	0 59	2 56.6	0.2847	0.1697	12 16	2.66
22	1 43	3 16.2				
23	2 25	3 35.7	0.2871	0.1675	12 12	2.65
24	3 4	3 55.2				
25	3 42	4 14.7	0.2894	0.1655	12 9	2.65
26	4 17	4 34.1				
27	4 50	4 53.5	0.2917	0.1634	12 5	2.65
28	5 22	5 12.8				
29	5 51	5 32.1	0.2941	0.1616	12 2	2.65
30	6 18	5 51.2				
31	7 6 43	− 6 10.3	0.2964	0.1597	11 59	2.64

GENERAL NOTES.

Lectures on Celestial Mechanics by G. W. Hill.—Professor J. K. Rees informs us that a course of free lectures on Celestial Mechanics by G. W. Hill will be given at Columbia College, beginning Oct. 15. We hope to have the lectures reported for this publication.

Professor William R. Brooks, Director of Smith Observatory, Geneva, N. Y., has received from Hamilton College the degree of Doctor of Science in recognition of his Astronomical discoveries.

New Durchmusterung.—Inquiries are made for information concerning the New Durchmusterung. If any reader knows when this work will be ready for distribution, it would be a favor to have the information.

The Andromeda Nebula.—A telegram received Sept. 20 from Mr. John Ritchie, Jr., at Boston states that a stellated condensation has been observed near the center of the Andromeda Nebula by Seraphimoff at Pulkowa, Russia. The information was cabled by Dr. Kreutz of the *Astronomische Centralstelle* at Kiel, Germany.

Efficiency of Administration at the United States Naval Observatory, Washington, D. C.—An interesting circular letter has been prepared and circulated for the views of astronomers and astrophysicists regarding the efficiency of the administration of the United States Naval Observatory. The source of the committee and the plan of work are outlined in this circular.

That there is need of re-organization of the United States Naval Observatory there can be no question. We hope for the success of this plan.

At the Second Conference of Astronomers and Astrophysicists, held at the Harvard College Observatory on August 20, 1898, the following resolution was adopted by unanimous vote:

Resolved, That a committee of three be appointed by the Conference to consider the question of the proper organization and function of the United States Naval Observatory; to draw up resolutions expressing different representative views; to obtain signatures of astronomers and astrophysicists of the country; and to present the same in person to the Secretary of the Navy by January, 1899, and to other authorities at their discretion.

Further, that said committee be instructed to co-operate with any other committees that may be appointed in this country to consider questions connected with the scientific functions of the National Government, and to take such further action as may seem to said committee expedient.

The following named persons were chosen as the committee: Edward C. Pickering, chairman; George E. Hale, secretary, George C. Comstock.

September 24, 1898.

Search for Andree.—From foreign papers as late as August 30, it is learned that the search for Andrée, the balloonist explorer has so far proved fruitless. The Swedish Nathorst expedition which is pursuing this search was on King's Charles land in the best of health, at the date above mentioned.

It is reported also that an expedition is to cross the Alps by a balloon, and that the party is to be provided with photographic apparatus. It is thought that a survey of portions of the Alps in this way will add much that is new and interesting to the friend of knowledge previously gained by Alpine climbers. Such a view of Sun, glaciers and numberless snow peaks would doubtless be sublime in the highest degree.

The Paris Exposition Telescope.—From the *British Journal of Photography*, Sept. 9, we learn that this great telescope, about which so much nonsense has been written and published, is really in construction, and good progress is being made with it by M. Gautier. It may rightly be called "giant" in size, if we can trust the figures of our authority, which are for clear aperture 1.25 meters (over 49 inches), for focal length 60 meters (more than 196 feet). This focal length must be wrong unless the method of construction is very unusual. The mounting of an object glass so large as this will tax the abilities of mechanical engineers not a little, if the movements of the great telescope are to be under the control of one person. Astronomers will watch the progress to completion of this great instrument. It will be a feature of great scientific interest at the coming Paris Exposition.

Astronomical Libraries.—We have often received requests for lists of books which may serve as a nucleus of a library for study and work in Astronomy. In Professor H. A. Howe's Elements of Descriptive Astronomy will be

found a good list of books and helps. They are listed as books of reference on pages 320-326.

In this issue is found a very useful article bearing on the same subject, by Dr. Herman S. Davis, of the Astronomical department of Columbia University.

The Sun-spot Minimum.—As the last sunspot maximum occurred in 1892-3, a period of solar calms may soon be looked for, in accordance with the well established spot cycle that has a course of 11 years.

Having taken solar observations for many years, I consider that the records for 304 days just past, divided into two parts of 152 days each, would yield some reliable indications if examined for comparative data. In such a comparison cloudy days are an indeterminable factor, but as in this California climate the days in which the Sun is continuously obscured are few and scattered, it is not probable that cloudiness materially changes the result, unless there be only a trifling difference in the compared data.

The term spot is used not only to denote single markings far apart from others, but also groups in which the components are sufficiently close to be regarded as the result of one disturbance, or, when not scattered over a greater area than about 12 degrees square. The instrument used was a four-inch telescope with a power of 60.

Between October 17th, 1897, and March 18th, 1898, the Sun was observed on 126 days, during which 30 spots appeared on the disk, 3 of which were of considerable size, having nuclei that measured from 10,000 to 20,000 miles in length. The various durations of the 30 markings caused the disk to present a spotted appearance on 98 days, which were interspersed with intervals of unspottedness amounting to 28 days, the longest interval being 14 days in the latter half of October. During a succeeding period of equal length, dating from March 18th to August 16th, in the present year, observations were taken on 113 days, 73 of which revealed a state of activity due to the coming and duration of 19 spots. In three cases the nuclei measured about 10,000 miles, and a nucleus double that length was conspicuous in the beginning of August. On 40 days the disk was an unbroken white tract, 16 consecutive days of unspottedness having occurred in April while the remainder were distributed in much smaller divisions. This noticeable decrease in solar disturbance may continue for a year longer, but the minimum is not an unimportant period, and should be carefully observed as the details of spot formation may have much significance at the time when the fury of solar storms are under some restraining power. ROSE O'HALLORAN.

San Francisco, August, 1898.

According to the above data the sunspot minimum seemed to be approaching but solar storms are fitful, and for a brief time on some occasions contradict the eleven year cycle, as in 1883, when a second maximum occurred, two years later than that of 1881, which came in accordance with theory. On the morning of September 2d, two weeks after the concluding date of the records above mentioned, a large penumbral marking appeared which soon proved to be one of the largest solar disturbances within the last eight years. In size of umbra, compactness and extent it is comparable only to that of February, 1892, and August, 1893. The details of its phases, which a clear sky fortunately enabled me to follow from the time that it appeared as a faint irregularity on the east limb, until it had grown dim on the west, where at the time of writing it still lingers in part, are of much interest at this stage of the spot cycle. At first it was one spot completely covering an area about 51,000 miles in length. Adjacent to its northeastern side were two

Sun-spot. Sept. 3d, 2:30 P. M.

small faint markings on Sept. 4th, and on the 7th these commenced to develop and since became large penumbral tracts thus forming with their larger companion a group extending over an area 140,000 miles in length.

Sun-spot, Sept. 9th, Noon.

As the umbra, which is of unusual size and durability, has the same heliographic latitude as a small spot that began its existence towards the center of the disk on August 11th, it may be a further development of that almost imperceptible disturbance. Otherwise it can not be traced as a continuance of any previous spot and it must have formed on the unseen surface of the Sun in the latter part of August. It extends from about south latitude 8° to 15° and may return to view towards the end of the month. ROSE O'HALLORAN.

San Francisco, Sept. 15th, 1898.

Large Sun Spot.—The following observations in connection with the large solar spot which appeared by rotation at the Sun's eastern limb on the morning of September 2d, may be of interest. When I first observed it, but a mere line of light separated it from the edge of the limb, no penumbra being visible, except on the north and south edges of the long umbral line; a bright aurora was seen the same evening. On the following day penumbra was visible on all sides of the umbra and the spot promised to be interesting, the changes from day to day since, being quite marked. Owing to atmospheric conditions the spectroscope could not be used until the 6th, when but little or no disturbance could be noticed in the vicinity of the spot. On the 7th though, a sudden outburst occurred, when the spectroscope was adjusted at 11:40 A. M. the entire region just preceding, and for some distance following, and also north and south of the spot was greatly agitated, the H_α line being reversed and distorted, small black jets projecting from either side of the line were noted in several places, and on opening the slit slightly, the flame and spike-like form of the disturbances could be clearly seen. At 12 M. intensely brilliant flames were observed over the large spot. Extending from the umbra to the edge of the penumbra on the east side, this phenomenon was particularly striking—the intensely bright scarlet flame nearly in the center of the dark absorption band of the spot spectrum being very interesting, the D_3 line was bright, and D_1 and D_2 and numerous other lines widened. At 12:05 P. M. a small dark line attached to the H_α line, extended obliquely towards the red end of the spectrum in the region just preceding the main spot. Observations were interrupted at 12:10 P. M. and could not be resumed again until 1:40 P. M. but the entire disturbance had then almost ceased, only a few slight reversals being noted. A 2-inch diffraction grating spectroscope attached to a 4-inch telescope was used. DAVID E. HADDEN.

Alta, Iowa, September 9th, 1898.

Astronomical Observatory at the University of California.—We have received a circular of very unusual interest for those interested in what may be called a School of Practical Astronomy. Its author is Armin O. Leuschner, Director of the Students' Observatory at Berkeley, Cal. The following extract will be of interest to all readers:

The trustees of the "Phebe Hearst Architectural Plan for the University of

California" have inaugurated an international competition to secure the most suitable plan for the erection of new buildings in place of the present ones. The buildings are to satisfy every need of a modern University of the highest rank.

Among the buildings contemplated is an Astronomical Observatory, especially adapted to the training of young men and women for the profession of astronomy in all its branches. This Observatory will replace the present Students' Observatory, and is to be erected on the most favorable point of the University site.

The new Observatory will not conflict with the Lick Astronomical Department of the University, located at Mount Hamilton and principally devoted to the prosecution of original work in the nature of observation and research. At the Lick Observatory students are admitted in general only after they have completed their studies in astronomy and the allied sciences, so that they may be on the footing of assistants to the astronomers of the Lick Observatory. They are supposed to have shown a marked ability for observation and independent research, and are admitted principally to receive from its astronomers a higher inspiration and to be guided by them in their first investigations in such special lines as can be best carried on at the Lick Observatory.

The Observatory to be erected on the University grounds at Berkeley is to complement the Lick Astronomical Department by being a center of instruction, both graduate and undergraduate. Its equipment should be such as best to serve the purposes of the highest instruction in all branches of astronomy.

Through the coöperation of the two astronomical departments, at Mount Hamilton and at Berkeley, a school of astronomy will be created which will offer unexcelled opportunities to intending astronomers for the acquirement of the knowledge necessary to their profession. The organization of such a school of learning is not intended to draw new members into a profession in which there is room for but a few, but to give the best possible preparation to those who desire to make astronomy their profession.

While the main function of the Berkeley department will be to give proper instruction to its students, the equipment of its Observatory should be such as to give ample opportunity for the higher work of research that the officers of instruction and the advanced students may be in a position to undertake.

Proposed buildings and principal equipment of the Observatory to be erected at the University of California under the Phebe Hearst Architectural Plan. Central dome, at least 25 feet in diameter, for an equatorial refracting telescope of aperture not exceeding 16 inches. Four smaller domes, 15 to 20 feet in diameter, for four smaller telescopes of 6 to 10 inches aperture; three of these to be refractors and one a reflector. Complete accessories of these instruments for visual, photographic, spectroscopic, and photometric purposes. Meridian circle room, 20 × 20 feet, for a four-inch Meridian Circle. Four transit rooms, 12 × 15 feet, for transit and zenith telescopes. All instruments so far mentioned, to be mounted on separate stone piers, directly brought up from the ground. The four smaller domes to be so placed that they shall not be obstructed by the principal dome and by one another. Astrophysical laboratory, 20 × 30 feet or more, containing stone piers set on the ground. Photometric laboratory, 15 × 15 feet or more, containing stone piers set on the ground. Photometric room, 25 feet long, 8 feet wide, height not less than 8 feet. Basement room for seismographs, 12 × 15 feet, solid piers. Basement room for clocks, 12 × 16 feet, solid piers. Basement room for batteries, conveniently placed. Four dark rooms, with not less than 60 square feet floor space each. Computing room or rooms, accommodating desks for fifty students. Three lecture rooms, accommodating one hundred and fifty, fifty, and fifteen students. Library, 20 × 30 feet or more. Instrument room, about 15 × 15 feet. General reception room for visitors, 12 × 12 feet. Lounging room for students during off hours, 20 × 20 feet. Suitable toilet rooms for men and women, closets, lockers. Director's office, 14 × 18 feet, and two other offices of same size. Residence for the Director and his family, being what is generally termed a ten-room house. Residence for two other officers of instruction and their families, flats or seven-room houses. Janitor's quarters. Three suites, each consisting of a room and study, for three fellows or assistants. Instrument shop, 15 × 20 feet; carpenter shop, 15 × 20 feet; small blacksmith shop. Heat, light and power will probably be supplied from a central station.

Mr. Justice Stahn, of Baltimore Astronomical Society, has recently written a useful popular article on the Wonders of Big Sun-spots.